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**GUIDANCE FOR OPTIMIZING REMEDY EVALUATION,
SELECTION, AND DESIGN**

by

Battelle Memorial Institute
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This document provides a general overview and explanation of key optimization concepts as they pertain to the FS, ROD, and RD cleanup phases. This document is not intended to provide guidance on determining site-specific risk-based cleanup goals, performing risk assessments, conducting site assessments and background investigations, or other site-specific contaminant characterization activities for which United States Environmental Protection Agency (U.S. EPA) and Navy guidance already exists. Rather, this document complements these important components of the site remediation process by providing recommendations for optimizing remedy selection and design.						
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ACRONYMS AND ABBREVIATIONS

ARAR	applicable or relevant and appropriate requirement
AS	air sparging
CAP	Corrective Action Plan
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	constituent of concern
COPC	constituent of potential concern
CMS	Corrective Measures Study
CSM	conceptual site model
CT	carbon tetrachloride
CVOC	chlorinated volatile organic compound
DAF	dissolved air flotation
DERP	Defense Environmental Restoration Program
DMM	dispose military munitions
DNAPL	dense, nonaqueous-phase liquid
DoD	Department of Defense
DON	Department of the Navy
DQO	data quality objective
DRC	Dispute Resolution Committee
EE/CA	Engineering Evaluation/Cost Analysis
ER	Environmental Restoration
ESD	Explanation of Significant Differences
FRTR	Federal Remediation Technologies Roundtable
FS	Feasibility Study
GAC	granular activated carbon
IR	Installation Restoration
LNAPL	light, nonaqueous-phase liquid
LTMgt	long-term management
LUC	land use control
MC	munitions constituent
MCL	maximum contaminant level
MCLB	Marine Corps Logistics Base
MEC	munitions and explosives of concern
MNA	monitored natural attenuation
MR	Munitions Response
NAPL	nonaqueous-phase liquid
NAVFAC	Naval Facilities Engineering Command
NCP	National Contingency Plan
NFESC	Naval Facilities Engineering Service Center
NORM	Normalization of Environmental Data Systems
NOSSA	Naval Ordnance Safety and Security Activity
NPL	National Priorities List

NPV	Net Present Value
NRC	National Research Council
O&M	operation and maintenance
OMMO	operation, maintenance, monitoring, and optimization
ORC [®]	Oxygen Release Compound
OU	operable unit
PA	Preliminary Assessment
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	perchloroethene
PNS	Portsmouth Naval Shipyard
POC	Point of Compliance
PP	Proposed Plan
ppb	parts per billion
PRB	permeable reactive barrier
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
RA-C	Remedial Action Construction
RA-O	Remedial Action Operations
RAO	Remedial Action Objective
RC	Response Complete
RCRA	Resource Conservation and Recovery Act
RD	remedial design
RFA	RCRA Facility Assessment
RFI	RCRA Facility Investigation
RI	Remedial Investigation
RIP	Remedy in Place
RITS	Remediation Innovative Technology Seminars
ROD	Record of Decision
RPM	Remedial Project Manager
SARA	Superfund Amendments and Reauthorization Act
SC	Site Closeout
SI	Site Inspection
SVE	soil vapor extraction
TCA	trichloroethane
TCE	trichloroethene
TPH	total petroleum hydrocarbon
U.S. EPA	United States Environmental Protection Agency
UST	underground storage tank
UUUE	unrestricted use, unlimited exposure
UXO	unexploded ordnance
VOC	volatile organic compound
WWTP	wastewater treatment plan
ZVI	zero-valent iron

1.0 INTRODUCTION

The Department of the Navy's (DON's) environmental restoration mission is to protect human health and the environment while supporting the defense mission by ensuring continued use of lands necessary for military operations at active Navy sites (DON, 2003). This mission is supported, in part, by an ongoing effort to improve the performance and cost-effectiveness of the Installation Restoration (IR) program and the Munitions Response (MR) program. The Navy's Environmental Restoration (ER) program encompasses both the IR and MR programs. Decisions made during the remedy evaluation, selection, and design phases of the ER program have significant risk and performance implications on site cleanup. Naval Facilities Engineering Command (NAVFAC) has been proactively involved in addressing these issues and facilitating the decision-making process through various approaches. These approaches include the development of policies and guidance such as this document; technical work groups; technology transfer tools; and training seminars (e.g., Remediation Innovative Technology Seminars [RITS]), and workshops. NAVFAC's policies and guidance documents related to environmental restoration are located on the following Web page: <http://enviro.nfesc.navy.mil>.

1.1 Background

Figure 1-1 summarizes the typical activities that take place at and near Navy installations. Most Navy facilities provide a variety of support functions for aircraft, submarines, and ships. Historic waste management practices associated with these activities have resulted in the release of contaminants to soil, sediment, and groundwater at Navy sites over the last several decades. Some examples include: (a) petroleum hydrocarbons released to soil and groundwater at leaking underground storage tank (UST) sites, tank farms, or former firefighting training areas; (b) historic equipment cleaning and degreasing operations that led to chlorinated solvent releases to the environment; (c) sediments that become contaminated through wastewater discharges or storm-water runoff containing chemicals such as polycyclic aromatic hydrocarbons (PAHs) or polychlorinated biphenyls (PCBs); and (d) other contaminant releases that could have occurred as a result of other typical activities at Navy installations, including municipal solid waste landfills, paint shops, plating shops, dry cleaners, and firing ranges.

The cleanup of Navy installations poses a major challenge because of the wide variety of activities conducted at these sites and the fact that most Navy installations are located in coastal regions with shallow groundwater and sometimes nearby ecologically sensitive habitats. It is estimated that more than \$4 billion is needed to complete the remediation efforts at the current Navy ER sites (DON, 2003). Navy guidance documents, such as this report, are intended to support the ER program goal of achieving environmentally protective site closeout at the least cost. Responsive stewardship of public resources also helps to minimize risk and ensure that site cleanup is addressed in an appropriate manner.

1.2 Regulatory Framework and Navy Policy

In 1980, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) was established to provide a legal framework for cleanup of contaminated sites. The Defense Environmental Restoration Program (DERP) was created when CERCLA was amended in 1986 through the Superfund Amendments and Reauthorization Act (SARA). Through DERP, the Department of Defense (DoD) formally adopted the CERCLA process for most environmental cleanups conducted by DON and other military services. In general, the Navy ER

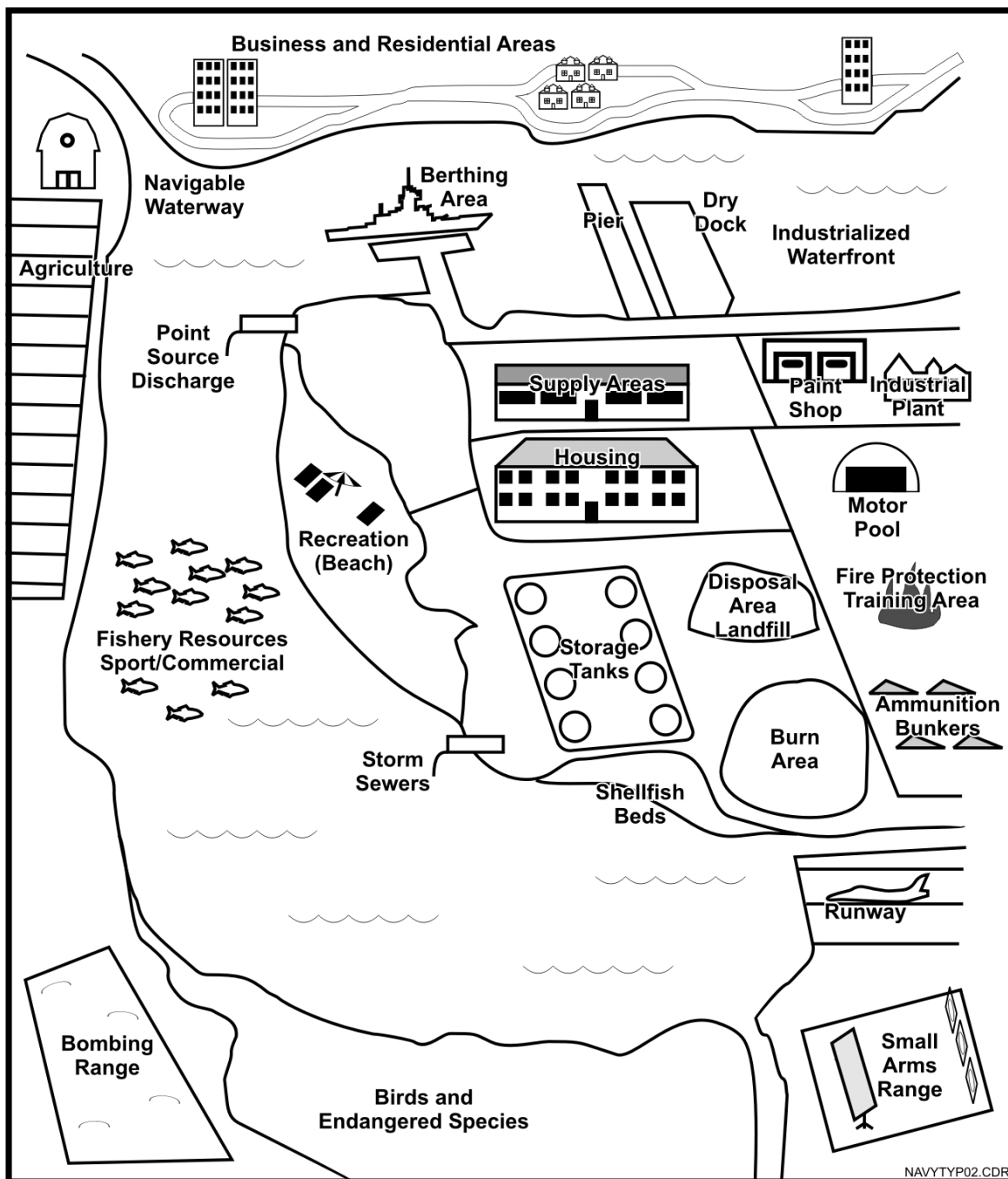


Figure 1-1. Typical Navy Facility

program adheres to the requirements set forth in CERCLA and its implementing regulation known as the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). At DON facilities, the Resource Conservation and Recovery Act (RCRA) also may be applied by regulatory agencies for corrective actions at sites or facilities impacted by past treatment, storage, and disposal practices. It is important to note that the majority of environmental releases (including accidental spills at DON facilities) occurred prior to the establishment of current environmental laws.

It is important to maintain consistency across the Navy and to implement cost-effective remediation and management approaches during any of these regulatory-driven processes. In order to accomplish this objective, NAVFAC has developed policies and associated guidance documents for various strategically important stages/phases of the ER process. For example, the Navy Remedial Action Operations/Long-Term Management (RA-O/LTMgt) Optimization Work Group has led the development of several guidance documents that serve as resources for Remedial Project Managers (RPMs) and focus on different phases of the cleanup process. The *Guide to Optimal Groundwater Monitoring* (Naval Facilities Engineering Command [NAVFAC], 2000) provides procedures to ensure that Navy monitoring programs are designed and periodically optimized to cost-effectively support program goals. The *Guidance for Optimizing Remedial Action Operations* (NAVFAC, 2001) provides step-wise optimization guidance during system operations.

Table 1-1 describes the major steps in the ER program. In addition to RCRA and CERCLA frameworks, several DON installations conduct remediation projects under State-led UST cleanup programs. State UST programs guide cleanup at most petroleum hydrocarbon-contaminated sites. UST programs are delegated to the State level, as part of RCRA, and may incorporate requirements that are more stringent than Federal UST regulation. Although RCRA, UST, and CERCLA processes for site remediation are similar, the terminologies for each project phase are different, as shown in Table 1-2. It should be noted that these are not necessarily linear steps, and that not all phases or milestones are needed for each project.

This guidance document helps to meet the objectives of Navy/Marine Corps policy related to the optimization of remedy selection and design. The Navy/Marine Corps optimization policy also relates to the RA-O and long-term management phases of the ER Program. At each phase, an evaluation of available data is required to ensure that all remedies are continually optimized. The policy further states that documentation within the Navy's NORM database is required of all optimization efforts. Periodic independent optimization reviews are highly effective and recommended by the NAVFAC Optimization Workgroup. The following three options (or combination thereof) are available to RPMs for the optimization review and are specified as choices within NORM:

- ❑ NAVFAC cleanup strategy review or optimization evaluation (coordinated through the Naval Facilities Engineering Service Center [NFESC])
- ❑ Internal technical review by the activity/division senior engineers
- ❑ Contracted, third-party review.

1.3 Objectives

The objective of this guidance is to provide procedures for consideration during the Feasibility Study (FS), Record of Decision (ROD), and remedial design (RD) for the optimization of remedial systems at Navy ER sites. This document is meant to serve as a companion to the previous optimization guidance identified in Section 1.2. Although the recommendations in this guidance are focused on optimization concepts prior to remedy implementation as applied to the FS, ROD, and RD, the implementation of overall optimization concepts could be applied during later stages of the cleanup process.

This document provides a general overview and explanation of key optimization concepts as they pertain to the FS, ROD, and RD cleanup phases. This document is not intended to provide

Table 1-1. Phases in the ER Process

Phase/Milestone	Description
Preliminary Assessment (PA)	The PA is a brief assessment that uses available historic information to determine the probability of and possible locations of potentially contaminated areas.
Site Inspection (SI)	The SI is a limited on-site investigation and includes a physical inspection of potential sites and, depending on site type, would include soil, surface water, sediment and/or groundwater sampling.
Remedial Investigation (RI)	The RI is a comprehensive assessment that includes characterizing the site (including nature and extent of contamination), determining the regulatory requirements, and conducting a baseline risk assessment for human health and the environment.
Feasibility Study (FS)	The RI provides the site-specific information needed in the FS to identify and analyze the range of remedial action options available at a given site. RPMs can refer to the several U.S. EPA guidance documents associated with preparation of an FS, such as <i>Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final</i> (EPA/540/G-89/004): http://www.epa.gov/superfund/action/guidance/remedy/rifs/overview.htm
Engineering Evaluation/Cost Analysis (EE/CA)	Non-time critical removal actions and interim remedial measures require completion of a less comprehensive feasibility review called an Engineering Evaluation/Cost Analysis (EE/CA). More information can be found in the U.S. EPA <i>Guidance on Conducting Non-Time Critical Removal Actions under CERCLA- OSWER Publication 9360.0-32</i> (1993): http://www.epa.gov/superfund/resources/remedy/pdf/540f-94009.pdf .
Record of Decision (ROD)	The ROD is the decision document that describes the background information on the site, the preferred remedial approach, and the rationale behind its selection. The ROD is completed after a Proposed Plan (PP) has been drafted and released to inform the public and obtain comments on the preferred remedial approach. The U.S. EPA <i>Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents</i> provides more detailed information on the recommended outlines and content for PPs, RODs, Explanation of Significant Differences (ESD), and ROD Amendments (EPA/540/R-98/031): http://www.epa.gov/superfund/resources/remedy/rods/ An Action Memorandum is the abbreviated form of a decision document for removal actions, except that the Action Memorandum is only required to be signed by the installation Commanding Officer, and not by the regulatory agencies.
Remedial Design (RD)	The RD is the design of the selected remedial action, which includes preparation of technical work plans, drawings, and specifications.
Remedial Action Construction (RA-C)	RA-C is the part of the remedial action phase in which a construction contractor cleans up the site or builds and installs a remediation system, and demonstrates that the system is functioning as designed.
Remedy in Place (RIP)	RIP is a milestone during the remedial action phase which indicates that the remedial action has been successfully constructed or implemented, and has been demonstrated to be functioning as designed.
Remedial Action Operations (RA-O)	RA-O is the part of the remedial action phase in which the ongoing cleanup work takes place, including operation and maintenance (O&M) support and ongoing monitoring to ensure that the system is operating properly and successfully. Some sites are cleaned up during the RA-C phase (e.g., excavation), and therefore may not require RA-O.
Response Complete (RC)	The RC milestone indicates that the remedial action objectives have been met and the site no longer represents an unacceptable risk to human health and the environment.
Long-Term Management	The long-term management of a site may be required following RC to ensure that conditions at the site continue to be protective of human health and the environment. This could include additional monitoring, land use controls (LUCs), and 5-year reviews.
Site Closeout (SC)	SC is reached when a site is acceptable for unrestricted use, unlimited exposure (UUUE) and there is no expectation of further funds to be expended at a site.

Table 1-2. RCRA, UST, and CERCLA Processes for Remediation of Contaminated Sites

RCRA	UST	CERCLA
RCRA Facility Assessment (RFA)	Site Investigation	Preliminary Assessment/ Site Inspection (PA/SI)
RCRA Facility Investigation (RFI)		Remedial Investigation (RI)
Corrective Measures Study (CMS)	Corrective Action Plan (CAP)	Feasibility Study (FS)
Draft Permit Modification		Proposed Plan (PP)
RCRA Permit		Record of Decision (ROD)
Corrective Measures Implementation	Remediation Work Plan	Remedial Design/ Remedial Action (RD/RA)

guidance on determining site-specific risk-based cleanup goals, performing risk assessments, conducting site assessments and background investigations, or other site-specific contaminant characterization activities for which United States Environmental Protection Agency (U.S. EPA) and Navy guidance (NAVFAC, 2002a; 2003a; 2003b; 2003c) already exists. Rather, this document complements these important components of the site remediation process by providing recommendations for optimizing remedy selection and design.

1.4 Document Organization

This document is organized as follows to provide relevant background information and a step-wise approach for Navy RPMs to optimize projects during the FS, ROD, and RD phases:

- ❑ **Overview of Optimization Concepts (Section 2.0)** – Includes a discussion of optimization concepts including conceptual site models, remedial action objectives, target treatment zones, treatment trains, performance objectives, and optimization and exit strategies.
- ❑ **Considerations for Optimizing Remedies During the FS (Section 3.0)** – Provides remedy optimization recommendations to consider during remedy screening, evaluation, and selection.
- ❑ **Considerations for Optimizing ROD Flexibility (Section 4.0)** – Provides recommendations to prepare a flexible ROD that allows optimization, technology transition, and cost-effective cleanup.
- ❑ **Considerations for Optimizing Remedies During the RD (Section 5.0)** – Provides remedy optimization recommendations to consider during remedy design.

Additional Information and Case Examples

Additional information and case examples are provided throughout the text and are contained in text boxes like this one. They are intended to provide guidance on additional information/resources and to expand further on key concepts presented in the text.

2.0 OVERVIEW OF OPTIMIZATION CONCEPTS

To incorporate remedy optimization concepts in the remedy selection and design phases of the ER program, several iterative steps require careful attention:

- ❑ Develop and maintain a conceptual site model (CSM).
- ❑ Identify clear, concise, and flexible **remedial action objectives** and revisit them periodically to incorporate current regulations, standards, requirements, and other precedents.
- ❑ Identify the **target treatment zone(s)** based on CSM and remedial action objectives.
- ❑ Develop **remedial alternatives**, including “treatment trains,” for each target treatment zone, incorporating typical life-cycle behavior. As part of this step, conduct a **life-cycle cost analysis** to evaluate individual unit processes and the total cost for each remedial alternative. The cost analysis should be refined throughout the remedy selection and design process.
- ❑ Develop realistic system **performance objectives** for each component of the treatment train that account for technology applicability and limitations.
- ❑ Develop an **optimization and exit strategy** for each component of the treatment train.

2.1 Conceptual Site Model

An important optimization component is the development of a well-defined CSM. Figure 2-1 shows the elements of a complete model. The CSM is a useful engineering management tool and helps to successfully manage a site through the ER process. The CSM summarizes the site conditions, the distribution of constituents of potential concern (COPCs), potential receptors and exposure pathways, and land use data available for a given site. The CSM is first developed during the PA/SI phase, but should be updated continually as new information becomes available (e.g., during the RI and field treatability tests) to enhance remedy selection and design. During the remedy implementation and long-term site management phases, the CSM should be updated as performance data are collected and analyzed to refocus the remedy(ies) as necessary based on an “observational approach.”

To reinforce the concepts, a CSM has been developed for a hypothetical landfill site with soil, groundwater, and sediment impacted by spills of light nonaqueous-phase liquid (LNAPL) and dense, nonaqueous-phase liquid (DNAPL). The CSM for the example site is provided in Figure 2-2. For the example site, cleanup is required to protect ecological receptors in the nearby surface water.

2.2 Remedial Action Objectives

Remedial action objectives are site-specific cleanup goals that are formed based on the COPCs, the impacted media, fate and transport of COPCs, the exposure routes, and the potential receptors identified in the CSM. The remedial action objectives should provide a clear and concise description of what the remedial action should accomplish at a given site.

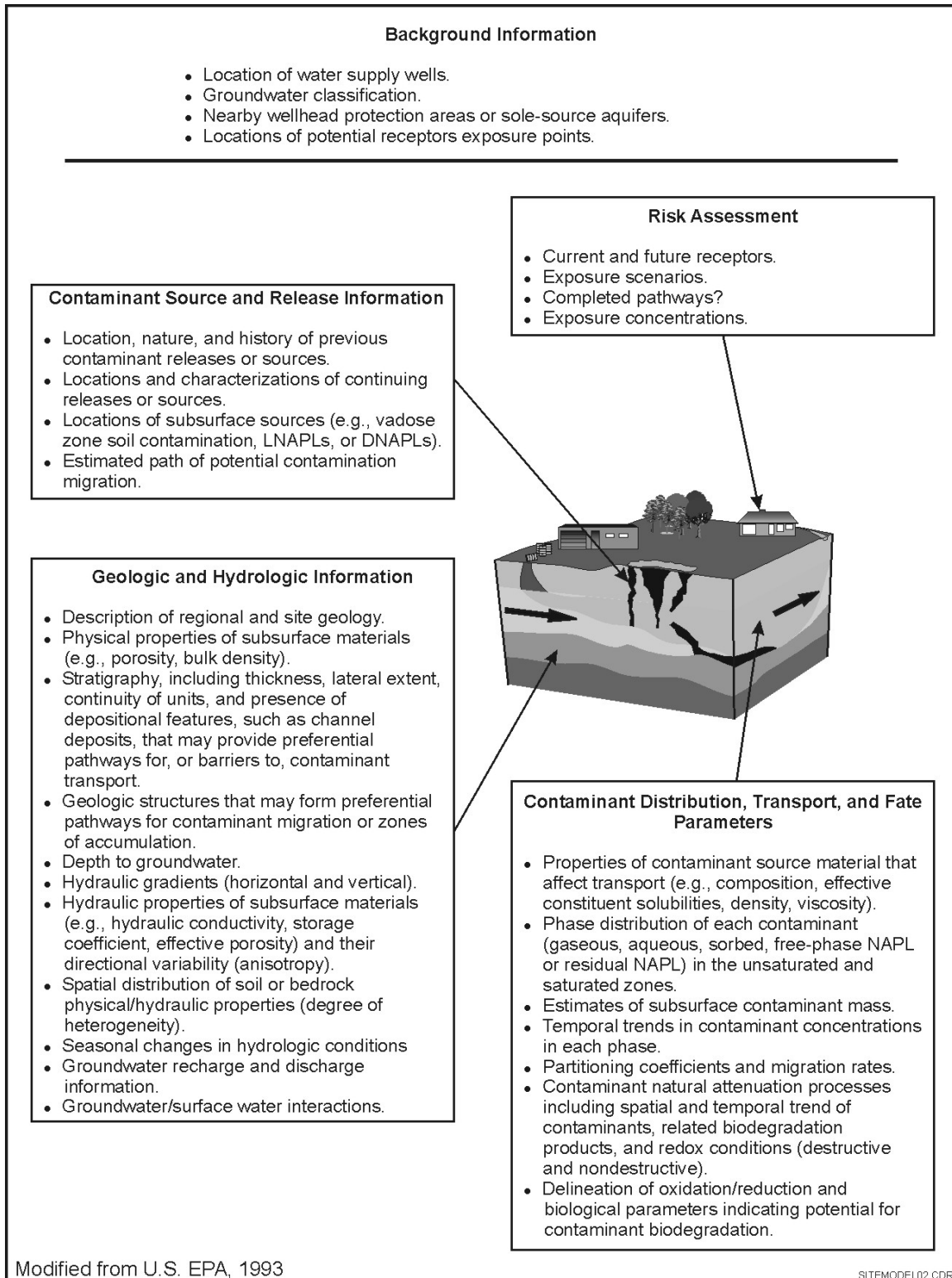


Figure 2-1. Elements of a Conceptual Site Model

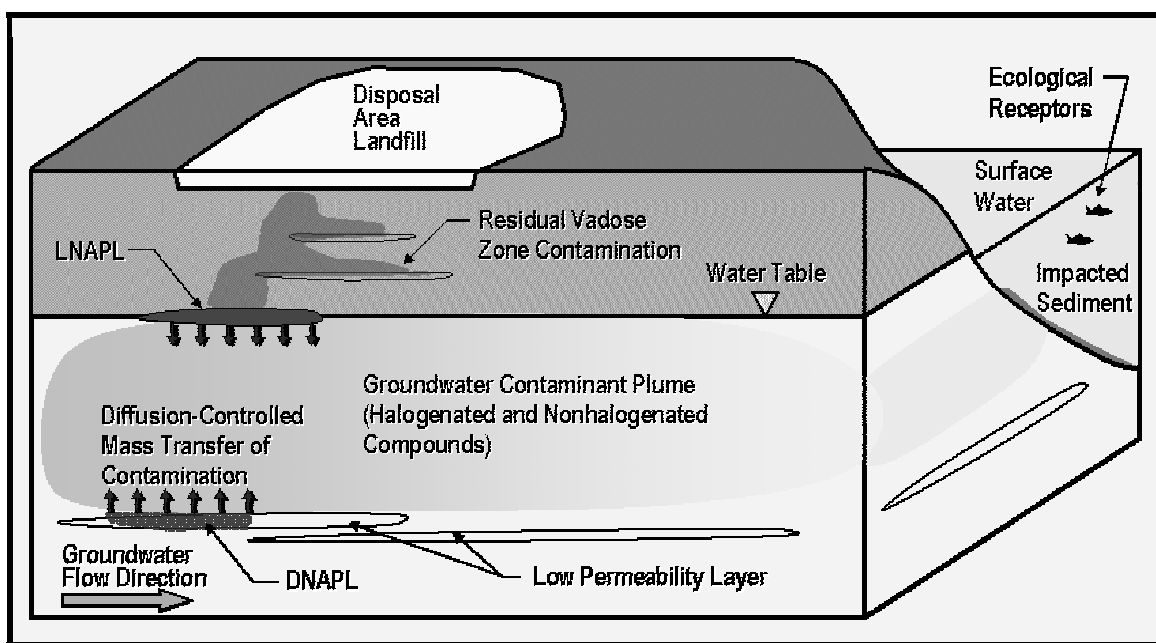


Figure 2-2. Example Site: Conceptual Site Model

Remedial action objectives often are based on the final cleanup goals for a site. Final cleanup goals are the concentrations in a given media that have been determined to be protective of human health and the environment. Cleanup goals may be established based on regulatory standards, such as maximum contaminant levels (MCLs) for groundwater, or site-specific risk-based values that have been calculated using site-specific data. For the example site (see Figure 2-2), the remedial action objective is to protect ecological receptors by preventing contaminant mass flux into surface water above risk-based concentrations.

It is important that the remedial action objectives (RAO) should be revisited during the remedy selection and design phases as regulations and project requirements change. Furthermore, whenever possible, it is important to develop flexible remedial action objectives rather than relying on fixed quantitative cleanup goals. For example, at LNAPL-contaminated sites, remedial action objectives should be based on goals that “remove LNAPL to the extent practicable” rather than on more static or fixed numerical requirements. This can be demonstrated by employing “best available technologies or presumptive remedies” for source removal/treatment, which significantly reduces further contaminant releases to sensitive receptors and/or environmental media.

2.3 Target Treatment Zone(s)

A target treatment zone is the volume or area at which the remedial action is determined to best apply. The zone is defined by the CSM and remedial action objectives, considering risk reduction, exposure routes, and the nature and extent of contamination. For soil or sediment sites, the target treatment zone may be limited to hot spots with elevated contaminant concentrations or may extend over the entire impacted area. For groundwater sites, the target treatment zone may encompass the source zone, the dissolved plume, localized areas with elevated concentrations within the plume, and/or the downgradient boundary of the dissolved plume. Figure 2-3 identifies potential target treatment zones for the example site.

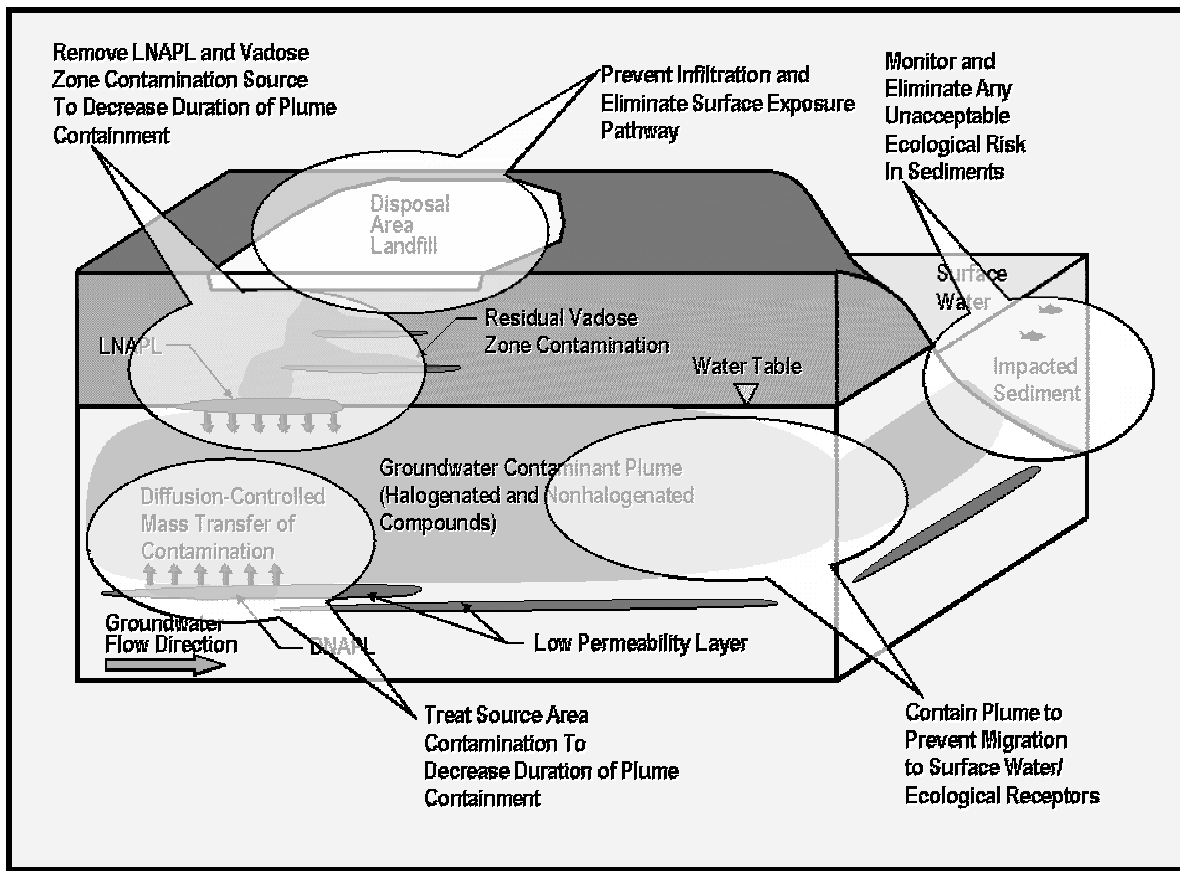


Figure 2-3. Example Site: Potential Target Treatment Zones and RAO Per Zone

The selection of the target treatment zone, as defined within the CSM, has a very significant impact on the life-cycle costs for a remediation project and often influences the length of time needed to achieve RC at a given site. In most cases, targeting hot spots or source zones can be a cost-effective means of removing a large amount of mass in a relatively short time period. However, such remedies are effective only if targeted and applied properly. In some cases, in situ technologies were initially considered ineffective, but further analysis indicated the target treatment zones were not well-defined and the technologies were not tested and specifically targeted to where the majority of contaminants were present. In situations like these, attempts to optimize can be difficult and futile. Accurate delineation of the source zone and hydrogeologic and geochemical parameters are critical for effective design and implementation of remedies.

As part of the optimization process, updating the CSM (and target treatment zones) during the implementation of the active remedy is very important. For example, during the NAPL source removal process, if it can be established through adequate monitoring that the dissolved plume is stable or receding, monitored natural attenuation (MNA) can be the final groundwater remedy without having to wait or resort to an additional active groundwater remedy to treat dissolved-phase contaminants.

Identifying Target Treatment Zones and the Sequential Application of Passive Cleanup Processes, Naval Weapons Station, Charleston, SC

Project Summary

A former UST site is the location of a mixed chlorinated aliphatic groundwater plume containing perchloroethene (PCE), trichloroethene (TCE), and 1,1,1-trichloroethane (1,1,1-TCA) in excess of 100 mg/L concentrations of total chlorinated volatile organic compounds (CVOCs) in groundwater. CVOCs at high dissolved concentrations and/or in the form of DNAPL distributed as ganglia are located in the low permeability sediments from land surface to approximately 10 ft below land surface. Identification of treatment zones and the application of sequential passive treatment technologies were instituted as shown in Figure 1. Loblolly pine trees were planted to treat contamination in the source area without encouraging the downward migration of solvents into the lower, more permeable formation. This created a mechanism for direct uptake, phytovolatilization, and improved soil structure to enhance biodegradation in the newly formed rhizosphere. Immediately downgradient of the source area, a permeable reactive barrier (PRB) consisting of zero-valent iron (ZVI) is used to treat high CVOC groundwater concentrations that have the potential to exceed the natural attenuation capacity of the aquifer. The PRB acts to cut off the pollutant load to the downgradient portion of the flow zone and the detached plume downgradient of the PRB can be naturally attenuated prior to discharge to a freshwater marsh. A mature lowland forest that incorporates direct uptake for phytovolatilization is part of the natural attenuation processes in the downgradient plume area beyond the PRB.

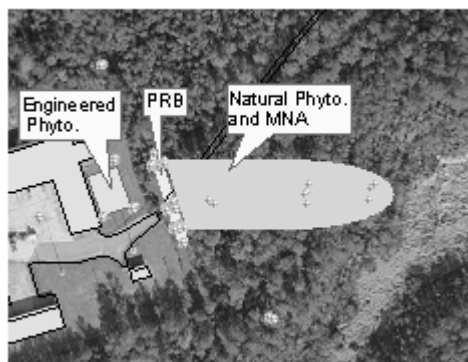


Figure 1. Identification of Target Treatment Areas

Optimization Strategy Employed

Identifying the target treatment zones aided in the subsequent identification of the appropriate level of remedial action required within each zone which allowed the project team to take advantage of the naturally occurring passive processes (monitored natural attenuation [MNA] and phytovolatilization) and to enhance these processes using low energy techniques (PRB and engineered phytoremediation) for treatment of the entire plume area. This optimized the remedial design and implementation by avoiding the higher costs associated with more aggressive engineered remedies and minimized impact to the natural landscape.

2.4 Multiple Remedial Technologies: The “Treatment Train” Concept

A key optimization concept is that of sequential implementation of multiple remedial alternatives, also known as a “treatment train.” A single remedial technology is rarely the most cost-effective approach throughout the life cycle of a site cleanup project. The treatment train concept emphasizes that multiple remedial technologies often are needed to achieve cost-effective remediation at a given site. Figure 2-4 identifies treatment trains or a series of technologies to be applied over time for each target treatment area in our example site.

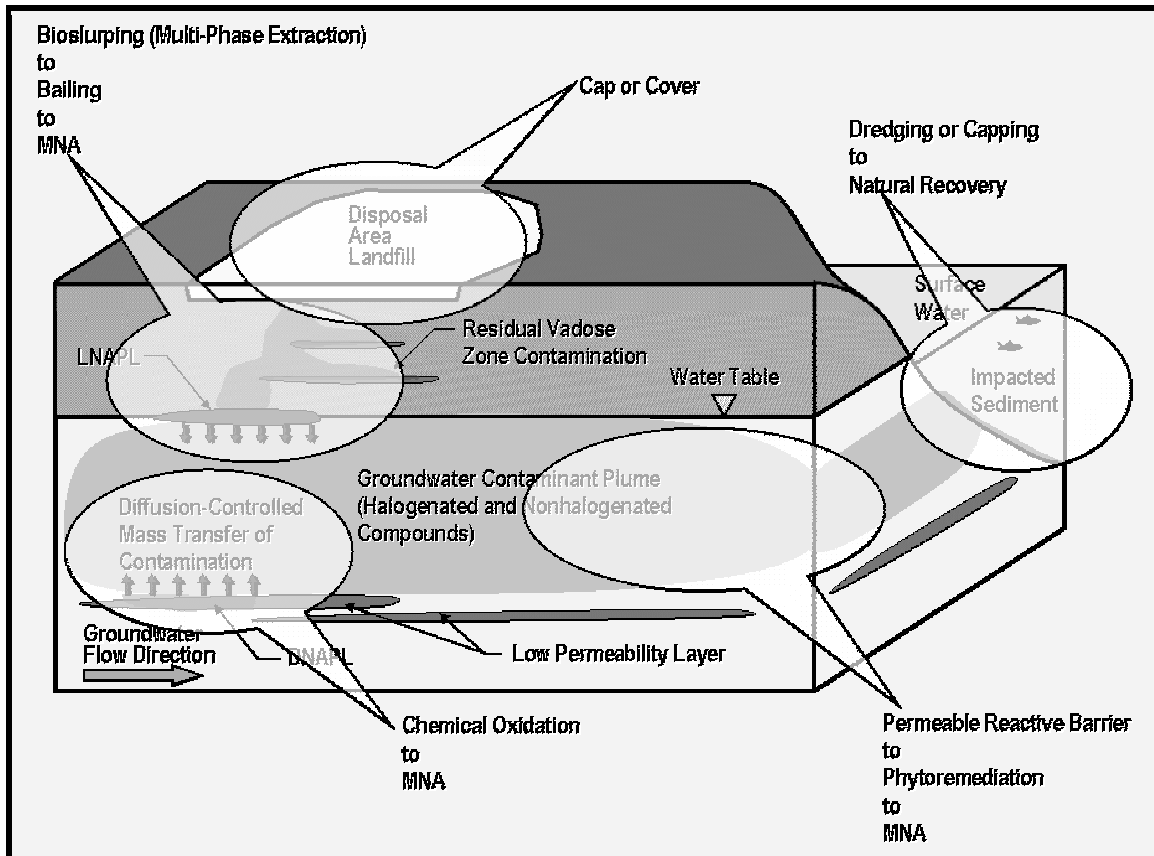


Figure 2-4. Example Site: Treatment Train Alternatives

The treatment train concept can be applied to several different aspects of a remediation project. It can include the use of multiple remedial technologies over time. It can encompass the concurrent use of multiple remedial technologies over various locations for the same contaminant and/or media. The treatment train concept can also entail the use of several different unit processes within a single remediation system. All of these perspectives on treatment trains are discussed below.

The importance of treatment trains in the wastewater industry offers a good analogy for the need for treatment trains in the remediation field. For example, conventional wastewater treatment is separated into preliminary, primary, secondary, and advanced systems. Preliminary systems remove bulk contamination such as large floating solids, grit, and possibly grease. Primary systems remove suspended solids through sedimentation. Secondary systems are typically biological processes such as trickling filters that remove the soluble and colloidal organic matter that remains after primary treatment. Tertiary, or advanced, wastewater treatment includes techniques that further improve the quality of wastewater and are typically directed at the removal of suspended solids and/or dissolved constituents such as ammonia, nitrogen, phosphorus, and metals.

Just as wastewater treatment systems may require multiple technologies to achieve the desired water quality, so often does site cleanup. For example, bulk contaminant removal at a petroleum- or chlorinated solvent-contaminated site may involve hot spot soil excavation as the first step in site cleanup. Following excavation, LNAPL removal can be achieved by implementing the appropriate remedial technology such as multiphase extraction or skimming. Following LNAPL reduction, further remediation of soil and/or groundwater may be necessary by active remedial

techniques to further reduce contaminant mass. Examples of active remedial techniques include bioventing, soil vapor extraction (SVE), and air sparging (AS). Application of these and other active remedial technologies can be considered analogous to primary or secondary wastewater

Treatment Train Approach to In Situ Treatment of Chlorinated Solvents in Low Permeability Soils in Conjunction with Natural Attenuation, Marine Corps Logistics Base, Albany, GA

Project Summary

The Navy completed four pilot tests of in situ treatment of CVOCs in a low permeability formation at Marine Corps Logistics Base (MCLB) Albany. The tests were conducted as part of the RD phase for Operable Unit (OU) 6 which covers base-wide groundwater. The first two tests consisted of injecting ethyl lactate and hydrogen into the formation to enhance the natural biodegradation that was already occurring. The other two tests evaluated the effectiveness of chemical oxidation using potassium permanganate and chemical reduction using zero-valent iron (ZVI). Soil “fracturing” was utilized in all tests to allow the injected chemicals to treat a greater area. The objectives of the pilot testing program were to help to determine the site-specific viability of each technology and to obtain critical design factors that would minimize life-cycle costs for the selected remedy.

Optimization Strategy Employed

During the initial stages of the OU 6 RD phase, natural attenuation modeling was performed for the existing base-wide groundwater plume. The objective was to determine what level of contaminants could be left to naturally attenuate within the time frames set in the ROD. Based on the modeling, active treatment was needed for trichloroethene (TCE) concentrations above 150 parts per billion (ppb), perchloroethene (PCE) concentrations above 20 ppb, and carbon tetrachloride (CT) concentrations above 100 ppb. The remaining plume areas are expected to naturally attenuate. This optimization step resulted in a significant reduction in the plume area requiring active treatment. The natural attenuation modeling also helped to support the use of a “treatment train” approach that included active treatment technologies in conjunction with the more passive and inexpensive remedy of monitored natural attenuation (MNA).

The focus of the pilot test program was to select the active technology in the treatment train that would be most suitable given the low permeability formation and other site-specific conditions. Results from both of the enhanced biodegradation tests were unsatisfactory. The ethyl lactate injections caused an 80% reduction in TCE after two months, but the levels rebounded within three months. The hydrogen sparge injections had minimal effect on CVOC concentrations in nearby monitoring wells. The more aggressive treatment techniques were found to have better performance. The potassium permanganate reduced CVOC concentrations to below detection limits within a few weeks and there was no rebound observed after six months. Potassium permanganate proved to have the greatest radius of influence at 50 ft and was effective for all CVOCs except CT. The ZVI was also very effective in reducing CVOC concentrations, but some rebound was observed near the edge of the treated zone. ZVI will be used in the CT plume, but will need closer injection points at approximately 25 ft.

The use of the above optimization strategies helped to reduce the size of the active treatment area, reduce the number of required injection points via fracturing, and helped to realize savings to the project through the use of innovative technologies.

treatment. Passive technologies that provide for a “polishing step” might be considered analogous to tertiary or advanced treatment. Examples of passive remedial technologies include enhanced bioremediation, passive bioventing, and monitored natural attenuation (MNA).

A treatment train that combines both an active and a passive remedial approach is an important strategy for achieving cost-effective site cleanup. The use of passive remedial technologies is likely an important component of site cleanup because of the difficulty in cost-effectively treating contaminants that are trapped in the subsurface. These contaminants are often trapped within low permeability layers or in pore spaces and their release rate is slow and diffusion-controlled. Examples of this approach are the application of air sparging or chemical oxidation to reduce elevated source area concentrations followed by MNA for groundwater contaminated with dissolved organic compounds. The concurrent implementation of multiple technologies may also be effective such as LNAPL removal coupled with the downgradient application of MNA.

Another way to apply the treatment train concept is to consider the selection of various unit processes within a single remediation system. For example, thermal stripping would involve an extraction unit, a condensation unit, a water treatment unit (or a holding tank for disposal), and an off-gas treatment unit. Each component in the treatment train is cost-effective for a specific purpose and over a specific contaminant concentration range. Selection of appropriate units and buying or leasing options with flexibility to change the treatment components should be an integral part of the treatment train design. Most remedial technologies consist of a treatment train or multiple unit processes.

2.5 Performance Objectives

Performance objectives are criteria that measure the operational efficiency and suitability of a particular remedial technology. They also help to document realistic performance goals and the practical limits of a particular remedial technology. Practical performance objectives should be established for each component of the treatment train. Performance objectives are typically distinct from remedial action objectives and final cleanup goals because they take into account typical engineering performance and the limitations of the individual technology. However, there may be instances where flexible remedial action objectives could be linked to performance objectives. For example, the remedial action objective of removing free product to the “extent practicable” using bioslurping could be linked to the performance objective of removing volatile organic compounds (VOCs) in the vadose zone to the “extent practicable” using SVE.

Also, performance objectives help to define what the expected effective operational range of a given remedial approach may be, and can allow for flexibility within the remedial decision process to discontinue use of a specific technology once it is no longer operating within its pre-determined cost-effective range. Figure 2-5 illustrates the need for performance objectives that

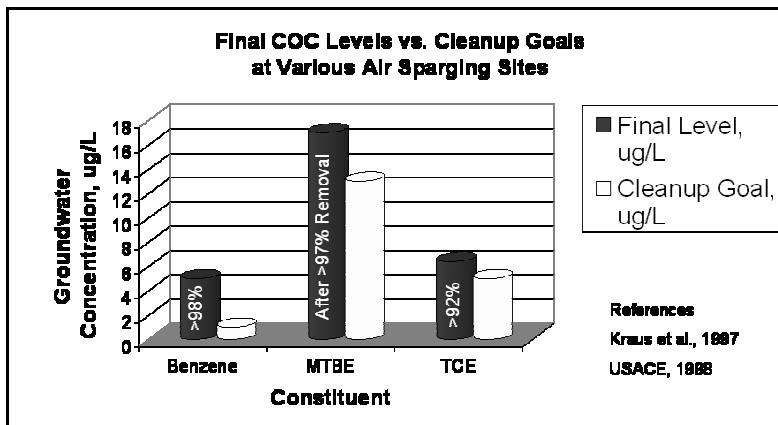


Figure 2-5. Example of Challenge in Obtaining Cleanup Goals with Active Technologies

allow for the utilization of a technology as long as it is operating within a cost-effective range. This figure is an example of the challenges faced in obtaining final cleanup goals for three common contaminants at air sparging sites. The graph indicates that, on average, the systems were very effective at reducing chemical concentrations with greater than 90% reduction of VOCs in the groundwater. However, even though air sparging was effective at removing a significant amount of the contaminant mass, it was unable to achieve final cleanup goals at several of the sites. This can result from slow, diffusion-limited mass removal that occurs when the remaining contamination is trapped and largely inaccessible to removal from the subsurface. Similarly, rebound following shutdown of active systems is often associated with trapped contaminant mass.

Example performance objectives for a bioslurping or multiphase extraction system would be as follows:

- ❑ Remove LNAPL to the extent practicable.
- ❑ Operate while cost-effective based on mass removal rate and unit cost per mass.
- ❑ Consider the ability of MNA to reduce residual contaminant levels to below risk-based level at surface water.

Figure 2-6 provides more examples of appropriate performance objectives for our example site.

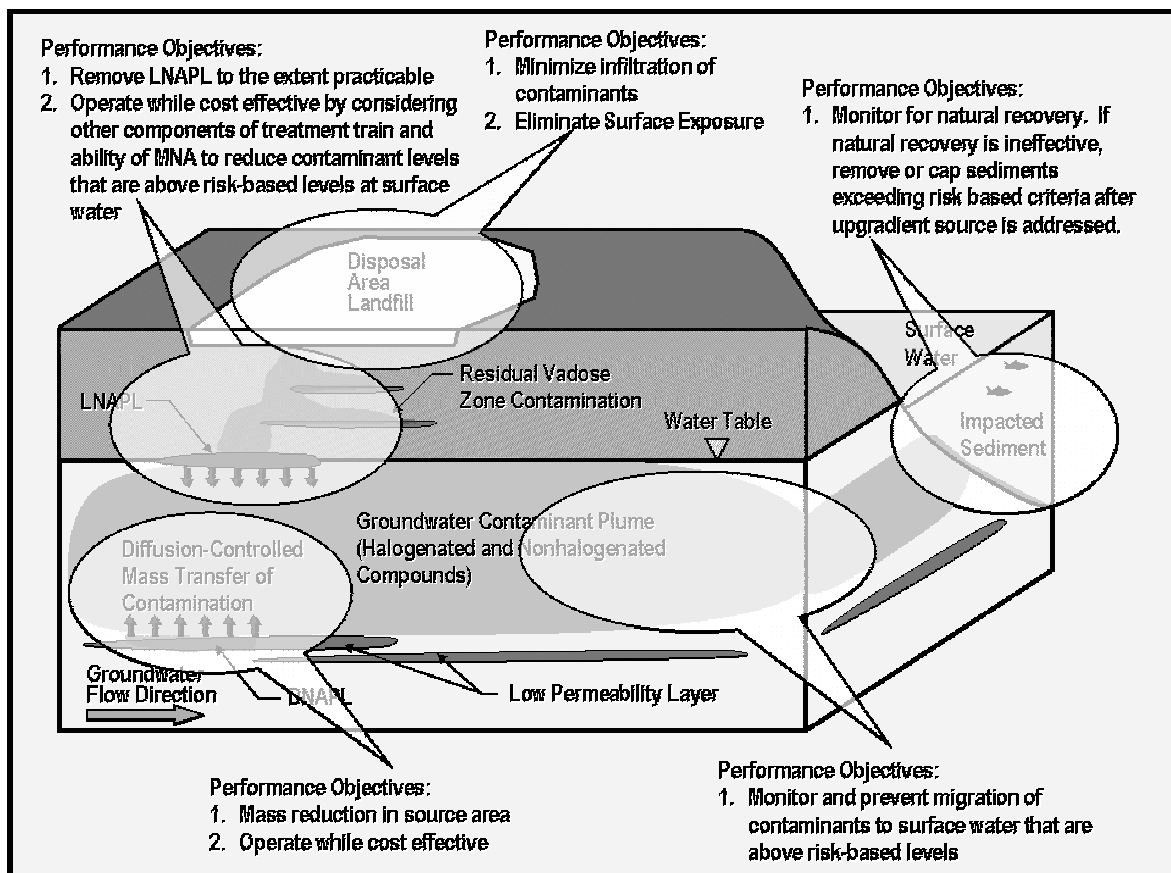


Figure 2-6. Example Site: Performance Objectives

2.6 Optimization and Exit Strategies

Lastly, optimization and exit strategies should be incorporated into the remedy evaluation, selection, and design process. Their development and documentation during the FS, ROD, and RD phases is necessary for cost-effective site cleanup, and ultimately for achieving timely RC and site closure. Optimization and exit strategies are a means of determining when it is time to stop, modify, or change a particular technology based on the achievement of previously established performance objectives.

Figure 2-7 provides a generalized optimization and exit strategy for a soil or groundwater remediation site. The diagram illustrates how performance objectives, system optimization, and rebound contingencies (primarily for most active technologies) can be combined into a decision-making framework for deciding when a given remedial technology has reached the end of its useful life.

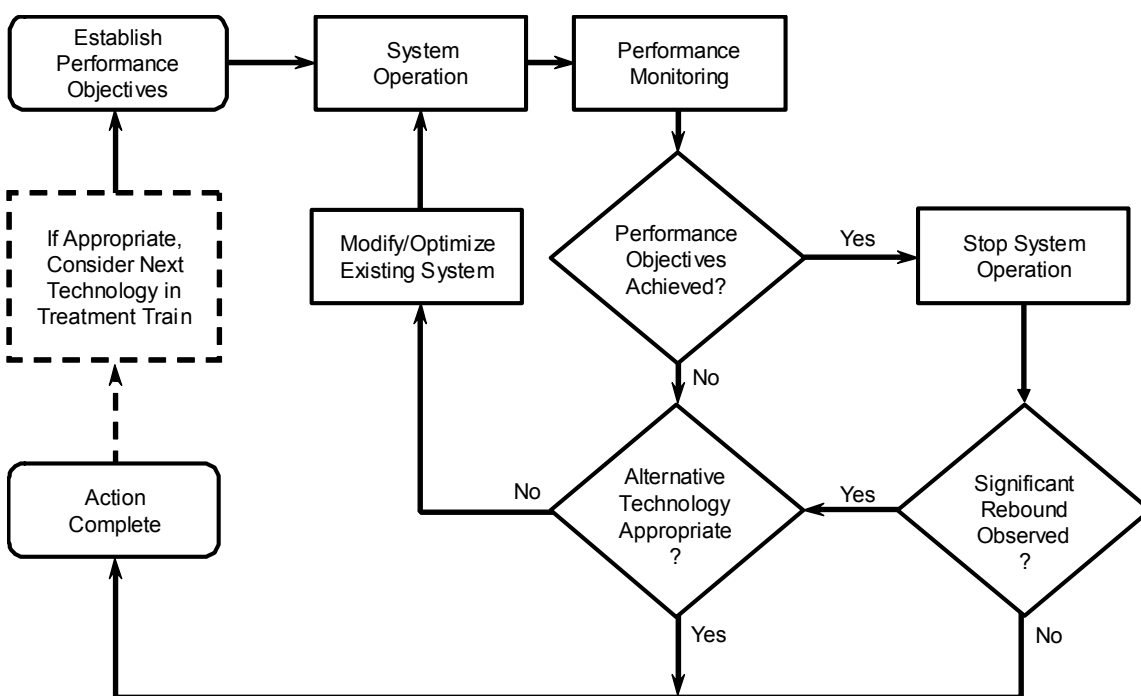


Figure 2-7. Generalized Optimization and Exit Strategy

System optimization is an iterative and systematic process that requires regular evaluation of the remedial design approach, performance, and operation of the technologies included in a specific remedial alternative. The principles of system optimization should be outlined during the remedy selection and design phases. Optimization during the RA-O phase is an important part of the implementation of the strategy, and may take many forms, from very simple and “common sense” steps to more complicated system changes and alterations. It may appear that a system has reached the end of its useful life cycle because mass removal rates are low or have declined dramatically over time. However, it may be that the system has not been appropriately maintained and/or that the system performance data have not been adequately evaluated to determine if the remedial system is operating as efficiently and effectively as possible. Furthermore, it is important to continually update and evaluate the CSM based on periodic monitoring data to ensure contaminated media in treatment zones are effectively targeted.

The remediation system should be evaluated and optimized before a determination is made about whether or not a system has achieved its performance objectives. A comprehensive discussion of system optimization is covered in *Guidance for Optimizing Remedial Action Operations* (NAVFAC, 2001).

3.0 CONSIDERATIONS FOR OPTIMIZING REMEDIES DURING THE FS

During the FS phase, technologies are identified and screened, and remedial alternatives are evaluated. Recommendations for optimizing remedies during the FS are provided in this section. A checklist is provided at the end of this section that summarizes the key considerations for optimizing remedies during the FS.

3.1 Initial Steps

Initial FS optimization steps include developing/refining the CSM and establishing remedial action objectives to address unacceptable risks identified in the RI. The development of a thorough CSM will help in the selection of the most appropriate remedy and its effective implementation. To develop an accurate CSM, it should be determined whether or not the available datasets are of sufficient quality (i.e., that proper collection and analytical quality assurance/quality control [QA/QC] procedures were followed to ensure data quality) and representative of current conditions. The site conditions and contaminant characteristics (phase, concentration, and distribution), as defined by the CSM, will drive remedy screening, evaluation, and selection decisions. Therefore, it is important that the CSM accurately reflect site conditions.

The following issues are common challenges related to the development of an adequate CSM:

- ❑ The incorrect definition of geology/hydrogeology, and related geochemical parameters, can lead to the selection of an inefficient remediation method.
- ❑ The inadequate definition of contaminant type, source areas, and distribution can lead to incomplete and/or prolonged site remediation.
- ❑ In addition to developing an accurate CSM, data collected as part of a site investigation should also be evaluated on its usefulness in aiding the selection and design of a remedial action. This involves implementation of the Data Quality Objectives (DQO) Process (U.S. EPA, 2000), which integrates the work of a multidisciplinary team to develop performance criteria for decision-making, form a consensus-based approach to understanding the problem, and ensure appropriate data type, quality, quantity, and locations. The DQO process is iterative and the final outcome is a design for collecting data (e.g., the number of samples to collect, and when, where, and how to collect samples), together with limits on the probabilities of making decision errors.

Additionally, the wording of the remedial action objectives is important and should be considered carefully when drafting the FS. Remedial action objectives should neither require a particular remedial technology to be operated until final cleanup goals are achieved, nor should they dictate the choice and/or duration of a proposed remedial action. Instead, the objectives should express how to protect human health and the environment. Some examples of remedial action objectives for soil, sediment, groundwater, and landfill sites are as follows:

- ❑ Limit human and ecological receptors from direct exposure to contaminants in surface soil.
- ❑ Remove contaminant mass in vadose zone to the degree necessary to prevent further degradation of the groundwater above groundwater cleanup standards and minimize the aquifer cleanup time.

- ❑ Reduce contaminant mass in the source area saturated zone to the degree necessary for natural attenuation (and/or enhanced bioremediation) capacity of the aquifer to stabilize plume migration and polish residual contamination in a reasonable time frame. NAVFAC has developed software to support this type of evaluation. The Navy's Natural Attenuation Software is available online at <http://www.cee.vt.edu/nas/> and is on the NMCI-approved list.
- ❑ Limit human and ecological exposure to contaminated sediments.
- ❑ Prevent infiltration of precipitation into landfill waste to minimize leachate and prevent surface exposure.
- ❑ Prevent constituents of concern (COCs) from reaching points of compliance (POCs) at concentrations above the cleanup goal.
- ❑ Prevent plume expansion beyond the POC.

3.2 Identification and Screening of Remedial Alternatives

By developing a clearly defined CSM, establishing remedial action objectives, and identifying target treatment zone(s), the RPM should be able to identify a concise list of potential remedial alternatives applicable to each treatment zone at a given site. The general categories of remedial actions are listed below and proceed from actions generally requiring lower logistics and/or costs to those actions requiring greater logistics and/or costs:

- ❑ No further action
- ❑ Land use controls (NAVFAC, 2003d).
- ❑ Containment and other engineering controls
- ❑ In situ treatment/mass removal
- ❑ Ex situ treatment/mass removal.

In considering the appropriateness of remedies that fall into one of these general categories, the RPM should consider that risk management (i.e., institutional controls and containment) may be more cost-effective than cleanup at certain sites. That is, a remedy can achieve protectiveness of human health and the environment through the elimination of exposure pathways or preventing contact with receptors, rather than by eliminating sources of contamination. Such an approach may be the only technically practical means of managing risks at sites involving complex, heterogeneous hydrogeology and recalcitrant contaminants, such as DNAPL. In addition, land use controls are often part of a treatment train used in conjunction with active and passive remedies (e.g., MNA to manage risks during remediation). Similarly, a combination of remedial action categories often are used in a treatment train approach such as in situ treatment/mass removal, containment, and land use controls.

The overall objective of the Navy's policy is to consider optimization steps throughout the ER process. Environmental restoration is a fairly mature field today, it is not necessary to consider every potential remedial alternative for the constituent and media of concern during the FS process. For example, the development of a focused FS can eliminate some redundancies and reduce the cost of developing an FS. Any relevant historical information such as treatability studies or actual remedies implemented at the same base or similar environmental conditions can be useful when developing a focused FS. To the extent possible, presumptive remedies, and those remedies that are successful and cost-effective (best available technologies), should constitute the

initial remedial alternative list. Presumptive remedies are standard technologies that can be applied at certain types of sites, such as municipal landfills or soils impacted with VOCs. They are designated by the U.S. EPA based on historical patterns of remedy selection, past experience, and technology performance. The U.S. EPA expects presumptive remedies to be considered at all applicable sites.

Another way to optimize remedies during the remedy identification process is to take a holistic approach and consider many or all contaminated sites at a base, rather than approaching each site on an individual basis. In general, if similar contaminants are present at more than one site, it can be more practical and cost-effective to select remedies that can treat those multiple sites. For example, if the quantity of contaminated soil at a site is small, excavation and off-site treatment and/or disposal may be the most cost-effective remedial option. However, if several sites contain soils that are similarly contaminated, then on-site treatment (e.g., a biopile) followed by on-site disposal (as clean fill or daily cover at the base landfill) may be the better, more cost-efficient option. Similarly, if an effective technology is being used at a site and the remedy is nearing completion, the associated equipment is likely to be available for reuse at a different site at the same installation with a minimum cost.

The number of alternatives to be carried over for a detailed evaluation typically is limited through a preliminary consideration of the potential effectiveness, implementability, and costs associated with each remedial alternative. Both effectiveness and implementability are qualitative criteria, but technology information available through the Navy and other agencies can facilitate a good screening process. Cost estimates can vary significantly for a given technology at different sites, and it is important to distinguish independent objective literature from vendor information to obtain reliable cost estimates. Therefore, resources such as the “Cost and Performance Reports” available on the internet can be valuable in making correct decisions (see Useful Web Sites for Remedy Selection text box).

3.3 Detailed Evaluation of Remedial Alternatives

The process of identifying and screening various remedial action alternatives is followed by a detailed evaluation of those alternatives that pass the screening. The U.S. EPA developed nine criteria to be used for the objective assessment of the various remedial alternatives (U.S. EPA, 1988). This framework is a first step in the evaluation process, and allows a comparison of the relative advantages and disadvantages for each remedial alternative and helps to justify the selection of the most appropriate remedial action. These nine evaluation criteria can be categorized into three groups: threshold criteria, primary balancing criteria, and modifying criteria. All threshold criteria must be satisfied for a remedial alternative to be eligible for selection. The primary balancing criteria are used to weigh major trade-offs among alternatives. The modifying criteria usually address public and regulatory acceptance of the alternatives. Table 3-1 provides a brief overview of these nine criteria. Note that a remedial alternative may be a single technology, but more often it is a combination of technologies employed sequentially in a treatment train remedial system.

The remedy evaluation process should consider effectiveness, site risk, the ability to implement the technology at a given site, and the cost to implement that technology. The trade-off in overall risks should be considered ranging from health risks associated with short-term versus long-term exposure to COPCs. Other risks that are important, but often overlooked are those associated with potential accidents and physical injuries to remediation workers. In order to quantify this tradeoff, it may be necessary to compare the risk reduction with the incremental cost in order to

Useful Web Sites for Remedy Selection

Several valuable on-line resources are available for remedy screening. These Web sites support the valuable process of a technical literature search for current information on technologies and methods. A few of the most comprehensive Web sites are listed below:

- ❑ **NAVFAC Environmental Restoration Web Site** – Provides a starting point for remedy evaluation. Provides a comprehensive review of the advantages, limitations, and other information for a wide variety of physical, chemical, and biological remediation technologies, as well as links to other relevant Web sites. Also includes Navy policy guidance related to optimization and other cleanup requirements. Link to <http://enviro.nfesc.navy.mil/erb/>. This link also includes Navy policy and guidance related to optimization and other cleanup requirements.
- ❑ **Federal Remediation Technologies Roundtable (FRTR)** – The FRTR Web site provides a comprehensive listing of technologies based on media and contaminant type and useful case examples, including cost and performance reports. Link to <http://www.frtr.gov>.
- ❑ **U.S. EPA Presumptive Remedy Web Site** – The use of U.S. EPA presumptive remedies can save time and money at a remediation site. Link to <http://www.epa.gov/superfund/resources/presump/general.htm>.
- ❑ **U.S. EPA Hazardous Waste Clean-Up Information** – This Web site for the U.S. EPA Technology Innovation Office advocates more effective, less costly approaches for the assessment and cleanup of contaminated waste sites, soil, and groundwater. Link to <http://clu-in.org>.
- ❑ **U.S. EPA Remediation and Characterization Innovative Technologies** – This Web site allows environmental professionals to search, view, download, and print information about innovative remediation and characterization technologies. Link to <http://www.epareachit.org>.
- ❑ **Other Related Web Sites:**
 - Ground Water Remediation Technologies Analysis Center: <http://www.gwrtac.org>
 - Interstate Technology Regulatory Council: <http://www.itrcweb.org>;
 - Remediation Technologies Development Forum: <http://www.rtdf.org>;
 - Environmental Security Technology Certification Program: <http://www.estcp.org>;
 - Strategic Environmental Research and Development Program: <http://www.serdp.org>.

identify the best remedial alternative. Figure 3-1 shows that some technologies will have a very high life-cycle cost, with little or no additional benefit in risk reduction. In addition, comparable life-cycle cost numbers should be developed (see text box on net present value [NPV]). Data gathered from prior optimization steps will help to provide reliable information to use during the evaluation process. Also, innovative technologies should always be considered, but they should be reviewed with special care. If information on certain remedial alternatives is limited, a range of probable costs can be determined from a decision-analysis, probabilistic cost-estimating approach that accounts for uncertainties in technology costs (ASTM, 2001).

Table 3-1. Summary of the CERCLA Nine Criteria

Category	Criteria	Descriptions
Threshold Criteria	Overall protection of human health and the environment	Addresses whether or not a specific alternative will achieve adequate protection and describes how the contamination at the site will be eliminated, reduced, or controlled through treatment, engineering, and/or institutional controls.
	Compliance with applicable or relevant and appropriate requirements (ARARs)	Addresses whether or not a remedial alternative meets all related federal and state environmental statutes and regulations. An alternative must comply with ARARs, or be covered by a waiver, to be acceptable.
Primary Balancing Criteria	Long-term effectiveness and permanence	Addresses the ability of a remedial alternative to maintain reliable protection of human health and the environment over time. It also considers the risk posed by treatment residuals and untreated materials.
	Reduction in toxicity, mobility, or volume through treatment	Addresses the preference for remedial actions that use treatment technologies that permanently and significantly reduce toxicity, mobility, and/or volume of contaminants.
	Short-term effectiveness	Addresses the period of time needed to implement the remedy and any adverse impacts that may be posed to workers, the community, and the environment during construction and operation of the remedy.
	Implementability	Addresses the technical and administrative feasibility of implementing a remedial alternative from design through construction and operation. Factors such as availability of services, materials, and operational reliability are considered.
	Cost	Addresses the total cost of a remedial alternative, including consideration of the capital costs, annual O&M costs, and net present value of these costs.
Modifying Criteria	State acceptance	Addresses the acceptability of a remedial alternative to state regulatory agencies.
	Community acceptance	Addresses the acceptability of a remedial alternative to the public.

The optimal remedial alternative will likely consist of a combination of remedial technologies applied in sequence (see Section 2.4 on the “treatment train” concept). More aggressive or active treatment technologies (e.g., multiphase extraction, chemical oxidation, air sparging, excavation) may be used for source area remediation. However, numerous case studies indicate that active remedies alone are often not cost-effective in achieving final cleanup goals due to diffusion-limited mass transfer and hydrogeologic constraints. Aggressive, active technologies can be followed by biological treatment processes (e.g., enhanced bioremediation and/or MNA) to form a cost-effective treatment train solution. The final portion of the treatment train will likely include MNA and/or long-term monitoring to ensure that concentration levels continue to decrease or remain at or below the cleanup goals for the site.

Figure 3-2 graphically represents the technology transition concept using the typical remediation performance curve for soil and groundwater sites. The optimization and exit strategy will provide a framework to assess when it is time to transition between active and more passive treatment technologies. The *Guidance for Optimizing Remedial Action Operations* includes several case studies demonstrating the use of in situ treatment trains where aggressive treatment of dissolved fuel hydrocarbons and/or chlorinated solvent source zones is followed by more passive technologies such as MNA or enhanced bioremediation (NAVFAC, 2001). The Navy’s Natural Attenuation Software provides a means for assessing the potential for such source reduction/MNA remedies and related time frames (available at <http://www.cee.vt.edu/nas/>).

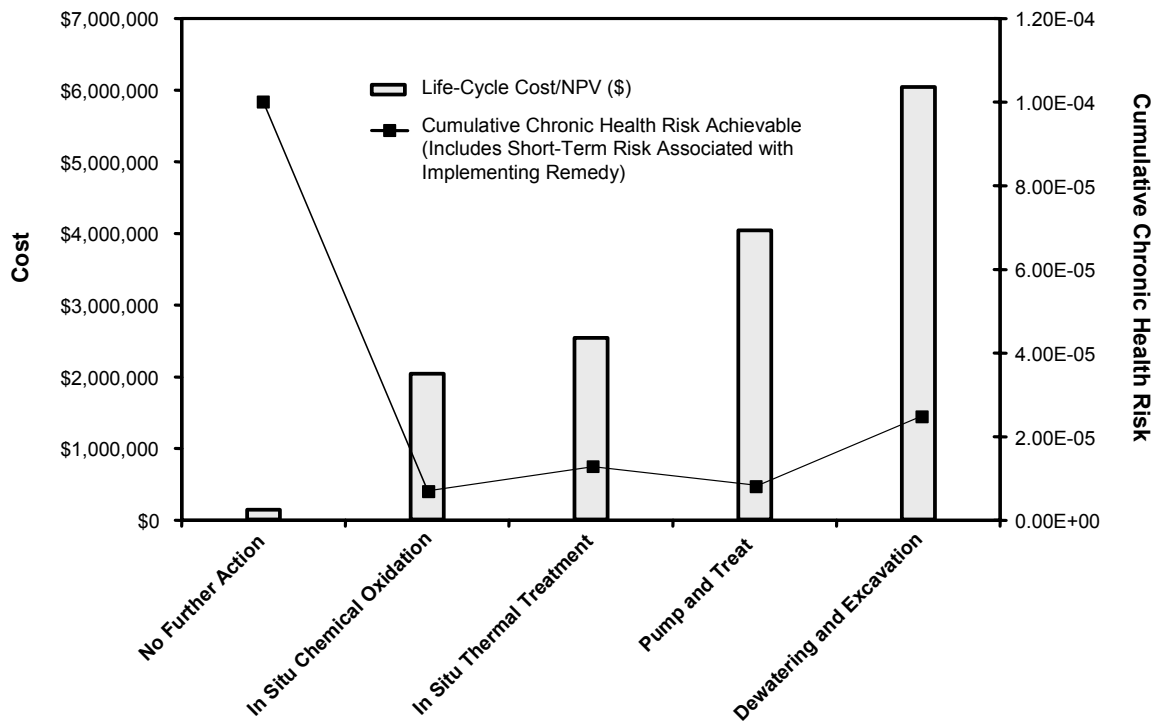


Figure 3-1. Hypothetical Example of Cost and Risk Comparison

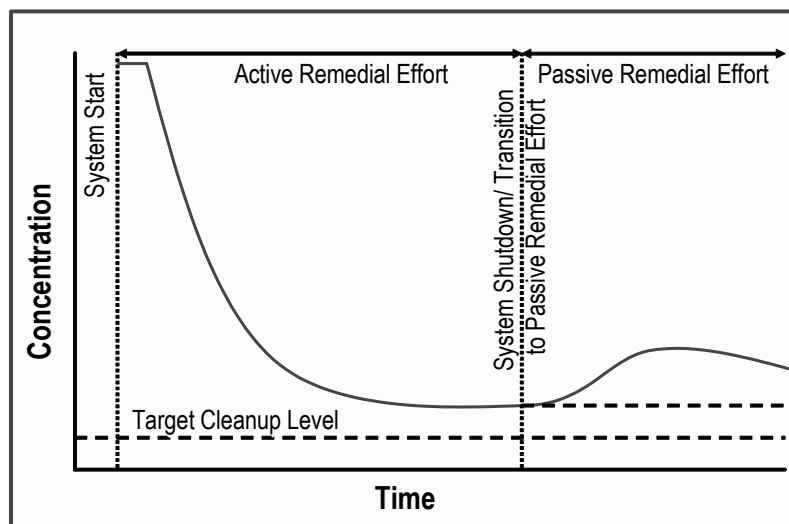


Figure 3-2. Technology Transition

Net Present Value and Total Cost

Life-cycle cost analysis within a FS follows the same procedures of any engineering economic analysis used to properly prepare costs for an engineering project. The life-cycle cost analysis typically includes the calculation of the NPV for each remedial technology under consideration. The NPV incorporates the time-value of money and can be thought of as the amount of money that, if invested now, would be needed to complete remediation, considering the interest rate on the invested amount. The following formula determines the present worth of a single payment at some future year:

$$P = F * \frac{1}{(1+i)^n}$$

where P is the present value,
F is the future value,
i is the interest rate per interest period, and
n is the number of compounding periods.

Interest rates are typically considered to vary from 0.5% to 10% for most NPV calculations. For example, at an interest rate of 6%, the present value for a payment of \$100,000 in Year Two of the remedial action would be as follows:

$$P = \$100,000 * \frac{1}{(1+0.06)^2} = \$100,000 * 0.89 = \$89,000$$

Although it is recognized that there is a time-value for money, Navy projects do not typically invest a lump sum amount at the beginning of a project to be used for the entire project life cycle. Therefore, the RPM should recognize that the NPV is useful in comparing and selecting technologies, but not for budgeting. The total cost of a remediation project may vary significantly from the NPV, especially at sites with long treatment durations. As an example, consider a life-cycle cost analysis for a pump-and-treat system versus source zone treatment coupled with MNA. The pump-and-treat system is expected to operate for 30 years. The in situ chemical oxidation in the source zone coupled with MNA of the downgradient dissolved plume is expected to last for five years. In this hypothetical example, the NPV of each approach are relatively close; however, the total costs vary significantly.

Example NPV Calculation

Item	Pump and Treat	In Situ Chemical Oxidation and MNA
Interest Rate	4%	4%
Number of Years	30	5
Capital Cost	\$1,000,000	\$2,600,000
Annual O&M	\$150,000	\$100,000
Present Value Factor ^(a)	17.29	4.45
Net Present Value ^(b)	\$3,593,500	\$3,045,000
Total Cost ^(c)	\$5,500,000	\$3,100,000

(a) Based on the calculation of present worth, given a uniform payment of O&M costs over a consecutive series of years. Calculation incorporates the interest rate (i.e., 4%) and number of years (i.e., 30 or 5).

(b) Net Present Value = Capital Cost + (Annual O&M Cost × Present Value Factor)

(c) Capital cost plus the annual O&M multiplied by the number of years.

The final step in the evaluation process is to identify performance objectives for each technology within the remedial technology train. Defining specific performance objectives is especially critical at sites with challenging features such as complex hydrogeology (such as sites with very “tight” or impermeable geology) or certain contaminant types (such as DNAPL or sites with continuing sources). These challenges and others may limit the ability of existing technologies to achieve stringent final cleanup goals. In many cases, due to diffusion-limited mass transfer, remedial alternatives may reach asymptotic mass removal levels before reaching final cleanup goals. Therefore, setting practical, technology-based performance objectives as part of a predetermined decision-making framework is important. This approach will allow for greater flexibility in system operation and also in transitioning between different remedial technologies as the remediation progresses.

Example performance objectives for active technologies include:

- ❑ Reduction of contaminant concentrations compared to baseline levels (e.g., 80-90% reduction in contaminant concentrations as compared to baseline levels).
- ❑ Mass removal to asymptotic levels (following appropriate system optimization to maximize the ability of the system to achieve mass removal to the extent practicable).
- ❑ Operate only as long as cost-effective (i.e., until the incremental benefit of further reduction in contaminant concentration is exceeded by the incremental cost of achieving those reductions).
- ❑ Operate until a combination of the above occurs (i.e., mass removal is asymptotic, concentrations measured in monitoring wells are asymptotic, and cost per unit mass removed is approaching an asymptotic level).

An example performance objective for passive technologies:

- ❑ Establish stable contaminant plumes via enhanced bioremediation (for sites with dissolved-phase groundwater contamination) followed by MNA to polish residual contamination.

Additionally, treatability studies may be appropriate during the FS phase to evaluate and to implement one or more treatment technologies within the treatment train. These studies generally involve additional characterization of untreated waste, evaluating the performance of a technology under actual site conditions, and determining critical design parameters for potential full-scale implementation. Treatability studies conducted during the FS can be used to support remedy selection (i.e., nine evaluation criteria), help determine performance objectives, help develop costs, and optimize design and operating conditions.

3.4 Media-Specific Considerations

3.4.1 Soil and Groundwater Sites

Based on information in the Navy’s Normalization of Environmental Data Systems (NORM) database, the majority of the sites in the ER Program have soil and/or groundwater impacts. It has become evident over recent years that the performance of many of the technologies used for the remediation of soil and groundwater (including NAPLs) is characterized by an initial phase of relatively high mass removal, followed by an extended period of much lower mass removal. This

phenomenon results in a gradual leveling off of cumulative mass recovered at the site over time. Figure 3-3 shows this typical performance curve. The first part of the curve can be referred to as the advective or high mass removal portion of the project, whereas the latter part of the curve can be referred to as the diffusion-controlled or low mass removal portion. For example, contaminants sorbed in the soil matrix and trapped in pore spaces are only available for treatment as they slowly diffuse into groundwater. Figure 3-4 illustrates the concept of preferential flowpaths in an aquifer and how contaminants are more easily removed as the water sweeps through these paths. Contaminants trapped in less accessible soil pores will be harder to remove due to the slow rate of diffusion.

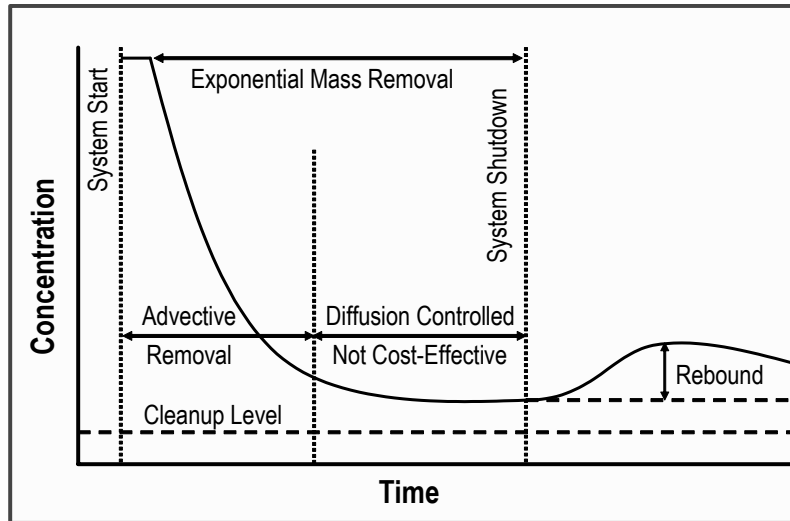


Figure 3-3. Typical Soil and Groundwater Remediation Performance Curve

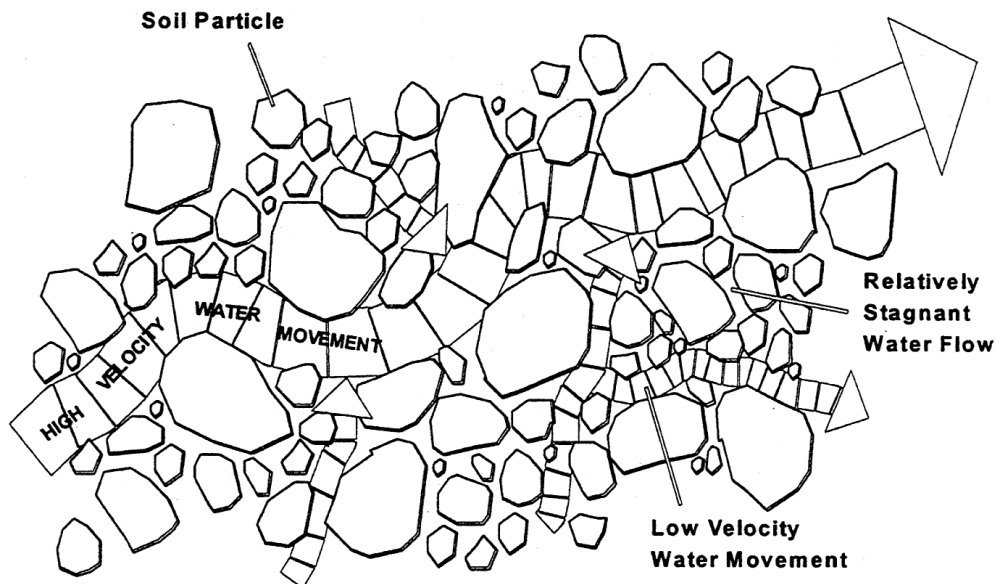


Figure 3-4. Effect of Groundwater Flow on Contaminant Removal

The diffusion-controlled portion of the curve often is reached prior to achieving final cleanup goals. This “asymptotic” mass removal behavior is a major technical challenge in achieving successful remediation and RC or site closeout at many sites. Contaminant rebound, which is often observed following system shutdown, may indicate a diffusion-controlled state or an untreated source area that was not effectively targeted.

Asymptotic mass removal becomes an issue when further system operation does not reduce contaminant levels below the final cleanup goals in a reasonable time frame, resulting in high unit mass removal costs. Several fate and transport processes occurring within an aquifer or vadose zone contribute to asymptotic mass removal behavior; including geologic and flow limitations and contaminant property limitations (Condit et al., 2002; Nyer et al., 2000; and NAVFAC, 2001). Understanding these processes and potential performance of remedial technologies under such conditions is necessary to develop an appropriate treatment train, logical performance objectives, and the optimization and exit strategy.

Geologic and Flow Limitations

Geologic heterogeneity can have a major impact on the performance of many in situ and ex situ treatment technologies. The permeability of soil in the vadose and saturated zones can vary by orders of magnitude at a given site. This geologic heterogeneity can lead to contaminants becoming trapped in low permeability layers such as silt or clay lenses over time, and also can influence the flow of water, air, and/or treatment reagents during active remediation.

For example, during active remediation with a pump-and-treat or air sparging system, a relatively large amount of mass will be removed by advective transport as water or air sweeps out the most accessible contamination located in sandy or more permeable layers. The less permeable layers, such as silt and clay lenses, may be bypassed by the main water or airflow paths within the subsurface. The removal of contamination in these less permeable layers is controlled by molecular diffusion. (Molecular diffusion is the natural tendency of chemical molecules to move from an area of high concentration to an area of low concentration and it is a relatively slow process.) During the later stages of a project, the contaminant molecules must diffuse through water or air from the low flow or low permeability areas to the high flow areas (i.e., preferential pathways) before recovery or in situ destruction. This leads to mass removal rates that decline over time as the most easily reached contamination is removed or destroyed first, and then diffusion-controlled mass transport processes begin to dominate.

In addition, the injection of fluids such as air, surfactants, chemical oxidants, or biological amendments may be limited by geologic heterogeneity within an aquifer. The injected fluids will tend to flow in the most permeable layers within an aquifer and may not come into direct contact with all of the residual contamination trapped in the pore spaces. Also, the mixing of injected fluids and groundwater may be incomplete or result in the contaminated groundwater being pushed outside of the treatment zone (Nyer et al., 2000, and National Research Council [NRC], 2003).

Contaminant Property Limitations

Several chemical and physical properties of contaminants can limit the effectiveness of their removal or destruction and therefore contribute to diffusion-controlled, “asymptotic” mass removal toward the end of a project. Several parameters play a role in the fate and transport of contaminants during active remediation, including sorption, volatility, solubility, and biodegradability as follows (Freeze and Cherry, 1979):

- ❑ **Sorption** – The movement of organic and inorganic chemicals in the subsurface is affected by their affinity for the soil matrix. Sorption can affect leaching from the vadose zone as well as contaminant movement within an aquifer. The degree of sorption depends on the properties of both the contaminant and the soil at the site. Slow desorption of contaminants from soil limits the ability to remove mass from the subsurface over time. Slow desorption can contribute to the diffusion-limited tailing behavior (e.g., concentration decreasing versus time) in pump and treat and other remediation systems. It can limit the effectiveness of many in situ treatment technologies, because many injected reagents and biological processes only react with contaminants in the dissolved phase. It also can reduce the effectiveness of ex situ separation treatment technologies such as soil washing.
- ❑ **Solubility** – The solubility of a contaminant in water determines the maximum rate at which mass can be removed from the subsurface when water is used as a carrier. Pure organic liquids or NAPLs are immiscible and only sparingly soluble in water. The NAPL constituents at the NAPL-water interface will dissolve very slowly into the flowing groundwater. LNAPLs such as petroleum hydrocarbons and DNAPLs such as chlorinated solvents are difficult to remove from the subsurface due to their limited solubility in water. NAPLs represent a significant continuing source of contamination because they are pure compounds and therefore have a high proportion of mass trapped in a relatively small volume. Although pools of DNAPLs are rarely found on low permeability layers, residuals are typically present in the form of ganglia and droplets trapped in the pore spaces and sorbed in the soil matrix, which serve as a continuing source and contributes to the diffusion-limited tailing behavior.
- ❑ **Volatility** – Because several types of organic compounds are highly volatile and not highly soluble, the use of air as a carrier in active remediation can be an improvement over the use of water as a carrier, because the movement of VOCs in the air phase is on the order of 10,000 times faster than in the water phase. For example, technologies such as air sparging in the saturated zone take advantage of this fact and can achieve significant mass removal within a shorter time frame. Air sparging systems typically operate for less than two years, whereas pump-and-treat methods can take several decades to achieve adequate mass removal. However, it should be noted that air-based technologies (e.g., AS and SVE) still experience diffusion-limited mass removal during the end stages of a project. The rate of removal will depend on the volatility of the NAPL (i.e., vapor pressure) and whether or not the air comes into direct contact with NAPL or with dissolved-phase contamination. Direct volatilization of the contaminant from the NAPL phase to air will result in higher mass removal rates compared to stripping from the water phase. Over time, mass removal tends to decrease as the contaminant is cleaned up in the vicinity of the main airflow paths and must travel farther before reaching the main air channels and volatilizing (Kavanaugh, 1996; Nyer et al., 2000; and NRC, 2003).
- ❑ **Biodegradability** – Organic contaminants are often amenable to either aerobic, anaerobic, or cometabolic biodegradation by microorganisms present in soil or groundwater. For example, petroleum hydrocarbons biodegrade more readily under aerobic conditions, and chlorinated solvents, such as tetrachloroethene, generally degrade more readily under anaerobic conditions (exceptions exist, such as vinyl chloride, which degrades under aerobic conditions). Typically, lighter molecular weight compounds degrade more readily than heavier molecular weight compounds. The complexity of the molecular structure and the strength of the bonds holding the

various elements together also play a role in the recalcitrance of some organic compounds. Other site-specific conditions can limit the rate of biodegradation including the lack of oxygen under aerobic conditions, the lack of suitable electron donors under anaerobic conditions, the lack of adequate micronutrients, high or low pH conditions, and other site variables that impact the growth and/or metabolism of microbes. In some cases, no microorganisms or only a limited population may exist at a given site with the metabolic capabilities to break down the COCs. As mentioned previously and analogous to wastewater treatment, biodegradation mechanisms can be exploited to achieve final polishing of contaminants that are diffusion-controlled. More information is available at the U.S. EPA's MNA Web site: <http://www.epa.gov/swenrust1/oswermna/index.htm>.

3.4.2 Landfill Sites

Commonly, landfill sites have soil and groundwater impacted by contamination (see Section 3.4.1). These sites have unique challenges that an RPM must consider during remedy selection and design. Treatment of all of the waste in a landfill typically is impractical due to the volume and heterogeneity of the waste in landfills. Also, risks are typically low at landfill sites, except for hot spots of groundwater or soil contamination resulting from the leaching or release of hazardous materials disposed at the site. Therefore, large landfill sites often require a combination of active treatment, containment, and long-term management, depending on the surface exposure, age of landfill, disposal history, and impacts to groundwater, including:

- ❑ Cap or soil cover to eliminate surface exposure pathway and/or minimize infiltration. Containment is the U.S. EPA Presumptive Remedy for landfill sites (U.S. EPA, 1996a).
- ❑ Groundwater containment downgradient of the landfill.
- ❑ Leachate collection and treatment.
- ❑ Landfill gas collection and treatment.
- ❑ Institutional controls to prevent unintended future land use.
- ❑ Long-term monitoring of groundwater and maintenance of the cap or soil cover.
- ❑ Hot spot removal of localized areas of wastes in soil and groundwater (rare and only in special cases).

A landfill site may only require a soil cover to prevent surface exposure and periodic groundwater monitoring if groundwater contaminants are not present or are not migrating. At the Portsmouth Naval Shipyard Jamaica Island Landfill, the Navy consolidated landfill waste, reducing the overall physical area, and implemented containment, monitoring, and long-term management of the site. The cleared area was used to enhance the beneficial use of the estuarine habitat surrounding Portsmouth Naval Shipyard.

3.4.3 Sediment Sites

Cleanup at sediment sites typically involves removal of contaminated sediments (via dredging) and aboveground treatment. This may be done to prevent further contamination migration, and/or to minimize exposure of ecological or human receptors. In situ remedial options that are avail-

able for sediment cleanup include monitored natural recovery, in situ capping, and in situ treatment. A brief description of each of the remedial options for sediments is provided as follows (NAVFAC, 2002b):

- ❑ Dredging is a removal activity that is most appropriate for high-risk sites where the benefit of sediment removal outweighs the risks of dredging and sediment resuspension. Once the sediment is removed, it typically needs to be de-watered and then treated using thermal, chemical, or biological methods. Off-site disposal at an approved facility may also be appropriate depending on the waste volume and characteristics.
- ❑ Monitored natural recovery relies upon the natural deposition of uncontaminated sediments over time and upon intrinsic contaminant attenuation. It is most applicable at relatively low risk sites to human and ecological receptors.
- ❑ In situ capping involves covering of the contaminated sediment in place with clean material to physically isolate it from the water column and aquatic environment.
- ❑ In situ treatment is an emerging technology and only a few approaches are technically and commercially viable. This approach promotes the in situ treatment of contaminants through several means such as phytoremediation, amendment addition, aeration, and other means.

Dredging may be used in combination or in sequence with in situ methods (i.e., treatment train) to achieve the most cost-effective cleanup.

The selection of a cost-effective remedy and the setting of realistic remedial action and cleanup objectives for sediment sites can be a complex and challenging process. Regulatory cleanup levels have not been promulgated for sediments and limited data is often available on the fate, transport, and toxicity of contaminants in the aquatic environment. In addition, the sediments near Navy installations have likely been impacted by a wide range of non-Navy sources such as municipal stormwater discharges and releases from private industrial entities. Navy policy on sediment sites requires identifying other sources of contamination, development of site-specific risk-based cleanup goals, consideration of background levels, CSM and DQO development, and containment of ongoing Navy sources before remediation can start (DON, 2002; NAVFAC, 2003c). More information on Navy sediment policies and remedy selection can be found in the *Implementation Guide for Assessing and Managing Contaminated Sediments at Navy Facilities* (NAVFAC, 2003c). This document contains practical guidelines for conducting sediment site assessments and remedial alternative evaluations at Navy sites.

3.4.4 Munitions Sites

Munitions sites can have soil and groundwater impacted by contamination (see Section 3.4.1) and can be an explosive hazard. The explosive hazard at munitions sites requires an RPM to follow a unique approach during remedy selection and design. Currently, the DoD and the Navy are establishing policy and guidance for munitions response actions under the Munitions Response Program (MRP). Key program drivers developed to date conclude that munitions response actions will be conducted under CERCLA. The two primary concerns at MR sites are munitions and explosives of concern (MEC), and munitions constituents (MCs), which are the chemical compounds within the MEC, including high explosives residues, white phosphorus, and metals (e.g., lead). Many munitions sites will require removal of some or most of the MEC, cleanup of the MC, and will still require institutional controls and containment in order to prevent site access and manage site risks. Munitions sites will also require the assistance of qualified

Landfill Site Remedial Design Strategy at Portsmouth Naval Shipyard, Kittery, ME

Project Summary

The Portsmouth Naval Shipyard (PNS) is a highly industrialized 278-acre island located in the Piscataqua River, a tidal estuary that forms the southern boundary between Maine and New Hampshire. Operable Unit 3 (OU3) consists of Site 8 (Jamaica Island Landfill) and two additional sites (Site 9 – Mercury Burial Sites I and II and Site 11 – Former Waste Oil Tanks 6 and 7) within the boundaries of the Jamaica Island Landfill (JILF). The JILF, which is approximately 25 acres of PNS, was a tidal mudflat that the Navy used as a disposal area from 1945 to 1978 for general refuse, trash, construction rubble, and various industrial wastes. The site was added to the National Priorities List (NPL) in May 1994 and subsequent remedial activities have been conducted under CERCLA. Following the RCRA Facility Investigation and revised risk assessment, the Navy prepared a FS for OU3 in 2000. A Proposed Plan for OU3 was issued January 2001 and the ROD for the site was signed in August 2001. The remedial plan included the consolidation of a 2.6-acre portion of the Jamaica Island Landfill nearest to Jamaica Cove onto the remaining 22 acres of the landfill, and subsequent creation of tidal wetlands (i.e., salt marsh and mudflat) in this area. The implementation of the first phase of the overall JILF remediation was initiated to enhance the estuarine habitat surrounding PNS, while at the same time providing the opportunity to consolidate Jamaica Island Landfill waste to an overall smaller area, which will be capped as part of the second phase of the remedial action. Consolidation activities were completed in September 2002 and the wetland planting was completed in June 2003. The second phase of the design includes construction of a cap over the remaining larger portion of the Jamaican Island Landfill and shoreline erosion controls.

Optimization Strategy Employed

Consolidation reduced the overall physical area of the Jamaica Island Landfill thereby minimizing the area to be covered, monitored and maintained as part of long-term operations, maintenance, and monitoring for the site. The cleared area could then be used for beneficial use for the enhancement of the estuarine habitat surrounding PNS. The public and the Residents Advisory Board for PNS supported the inclusion of tidal marsh creation as part of the overall Jamaica Island Landfill Remedy.



Figure 1 - Salt Marsh Establishment After Consolidation and Backfilling

EOD or UXO personnel and additional explosive safety plans and reviews by the Naval Ordnance Safety and Security Activity (NOSSA) (e.g., explosives safety submission, after action reports). Considerations in selecting a remedy at a MR site can include the type, age, location, soil or rock type, number of targets, number of target areas, and size of the surrounding human population. Another consideration is the accessibility of the MEC (e.g., underwater, in steep terrain) as well as the completed exposure pathways that may exist to MEC or MC at the site. For this reason, it is important to develop a comprehensive CSM for the site. In addition, specific data quality objectives must be established early in the investigative phase to help guide the data collection process leading to selection of a remedy at the site. Specific methods to address the explosive safety hazard at a MEC site include:

- ❑ Land use controls which include both institutional controls and engineering controls to prevent or reduce risks to human health and the environment;
- ❑ Surface removal which will remove MEC from the surface of the work area;
- ❑ Subsurface removal which will remove MEC from the work area to a specified depth.

The chemical constituents of a MC site can be addressed like other IR program contaminants in soil, groundwater, and sediments. After the explosive risk has been mitigated, methods include:

- ❑ Passive treatment (i.e. monitored natural attenuation);
- ❑ Hot spot removal of localized areas of wastes in soil and groundwater;
- ❑ Land use controls which include both institutional controls and engineering controls to prevent unacceptable future land use;
- ❑ Cap or soil cover to eliminate surface exposure pathway and or minimize infiltration;
- ❑ Active treatment (i.e. bioremediation, permeable reactive barriers, etc).

Munitions Investigation and Cleanup at Naval Air Facility, Adak, AK

Project Summary

The former Naval Air Facility at Adak Island, AK had been used for more than 50 years, dating back to WWII, for a variety of military support roles. These included the handling, use, storage and disposal of military munitions which led to the potential for a number of sites on the military reservation to be contaminated with MEC. While the Navy operated the base at Adak, munitions-related hazards were successfully managed by means of a public awareness program as well as access restrictions for areas known to contain munitions or munitions remnants. In 1995 Congress included the base at Adak on its closure list, and the last military operations ended there in 1997. With the closure of the base, it became necessary to address munitions hazards in such a way that private economic reuse by nonmilitary personnel would be possible. The Navy has been involved in completing environmental investigation and cleanup in preparation for transferring the base to private ownership and reuse and to a publicly accessible wildlife refuge. Because Adak was listed on the NPL (Superfund) in 1994, the approach for investigation and cleanup of past contamination (chemical contamination as well as munitions) was required to be performed under the framework provided by CERCLA.

Typically, past CERCLA-based investigation and remediation projects— including those conducted at Adak—relied on well-developed regulatory guidance, past precedents, and applicable, relevant, and appropriate environmental regulatory requirements. Although CERCLA provides a mature, well-developed framework for investigation, decision making, and cleanup of sites with chemical contamination, it provides no specific guidance for determining cleanup requirements at sites with potential explosive hazards associated with munitions. The need for investigation, decision-making, and a cleanup process that considered the needs of all stakeholders (i.e., Navy, regulatory agencies, U.S. Fish and Wildlife Service, prospective future land owners, tribal interests, and community members) with respect to the remediation of hazards associated with MEC soon became apparent.

Optimization Strategy Employed

To separate the munitions cleanup from the cleanup of chemical contamination, the Navy, U.S. EPA Region 10, and the State of Alaska agreed to create a separate Operable Unit (OU) B. To work toward an agreement on how to conduct the investigation and cleanup of the sites within the newly designated OU B, senior managers representing the Navy, U.S. EPA, and the State of Alaska formed a Dispute Resolution Committee (DRC). Rather than dictating a specific resolution to each of the issues under dispute, the DRC directed the formation of a project team composed of project managers from the Navy, U.S. EPA and the State of Alaska, as well as representatives from the U.S. Fish and Wildlife Service, the Aleutian/Pribilof Island Association (representing tribal interests), and The Aleut Corporation (the intended reuse authority). Support to this team was provided from technical consultants with expertise in munitions use, explosives safety, risk assessment, community relations, and munitions detection and remedial technology. This team was chartered with developing a Remedial Investigation and Feasibility Study (RI/FS) work plan for OU B that met the needs of all stakeholders. To foster an atmosphere of clear and open communication among the stakeholders, the Navy employed the services of a professional facilitator. In June of 2000, the constructive relationship enjoyed by members of the OU B PT made it possible to complete its task of reaching agreement on an RI/FS work plan a little less than a year after the team was formed. The success of the partnered approach used by the Adak Project Team continued long after the completion of the RI/FS work plan. The team continued to work as a group to arrive at cleanup decisions based on the information gathered during the RI/FS.

This team approach was aimed at optimizing the resources available to arrive at expedited risk based decisions concerning remediation of MEC sites on Adak. Among the innovations developed by the project team are:

- ❑ Developing a risk-based preliminary assessment screening approach for sites to categorize sites requiring the following:
 - Immediate response to reduce munitions hazards;
 - Additional investigation or information to determine the need for further cleanup; or
 - No further action to address potential munitions hazards.
- ❑ Developing sampling methodologies and standard operating procedures to gather necessary data at sites where the project team felt there was a need to determine the nature and extent of munitions contamination;
- ❑ Defining performance requirements for munitions detection systems
- ❑ Developing and implementing field based validation procedures for munitions detection systems to verify and document that they met the required performance standards for the project.

As a result, in December of 2001, the Navy, State of Alaska, and U.S. EPA Region 10 signed a ROD for 131 sites in OU B, for which much of the cleanup work had already been accomplished.

FS Optimization Checklist

Conceptual Site Model

- ☐ Contaminants, sources, and release information
- ☐ Contaminant extent, fate, and transport defined
- ☐ Human and ecological receptors identified
- ☐ Exposure pathways and exposure concentrations identified
- ☐ Geology and hydrology defined (including stratification and low permeability zones, aquifer characteristics, flow gradients and velocities, etc.)
- ☐ Land use assumptions identified
- ☐ DQOs developed

Remedial Action Objectives

- ☐ Focused on protection of human health and the environment
- ☐ Do not dictate the choice and/or duration of a proposed remedial action
- ☐ Consider POC for contaminants

Target Treatment Zones

- ☐ Identify target treatment zones
- ☐ Focused on risk reduction (consider evaluating risk reduction versus cost of remedial alternative)
- ☐ Source zone(s) considered
- ☐ Protecting and/or treating near exposure points considered

Treatment Train

- ☐ Identify multiple technologies (i.e., treatment train) for each target treatment zone (contaminant concentrations change over time; therefore the most cost-effective treatment approach changes with time)
- ☐ Evaluate effectiveness, implementability, and cost of each treatment train (e.g., U.S. EPA nine evaluation criteria)
- ☐ For alternative costs, include total cost and NPV

Performance Objectives

- ☐ Identify performance objectives for each component of the treatment train.
- ☐ Consider technology limitations, typical remediation performance, and cost-effectiveness.

Optimization and exit Strategy

- ☐ Identify how performance objectives will be used to transition to the next treatment technology in the treatment train.
- ☐ Clearly indicate that optimization will be an ongoing process during system operation.
- ☐ Incorporate rebound evaluation period (e.g., 1 year for groundwater to evaluate seasonal variation)
- ☐ Incorporate a contingency for rebound (e.g., reinstate system operation if significant rebound is observed)

Miscellaneous

- ☐ Consider a focused FS
- ☐ Consider U.S. EPA presumptive remedies to streamline FS process
- ☐ Consider potential remedial action at other sites at a base/facility. Economies of scale associated with multiple sites may result in certain options becoming more cost-effective from a holistic view.

4.0 CONSIDERATIONS FOR OPTIMIZING ROD FLEXIBILITY

This section provides overall recommendations for optimizing ROD flexibility and a checklist that summarizes key considerations.

After evaluation of the nine criteria is completed within the FS, a PP is developed that includes the selected remedy. The PP is a concise document for wider distribution among the public and other relevant parties. Its purpose is to describe the selected remedy and to obtain final comments on the remedy. Within the PP, it is important to include the remedial action objectives and multiple remedial alternatives with flexibility to change the remedy based on performance objectives, exit strategy, and remedial action objectives. Once the PP is accepted by the regulatory agencies, the remedy selection is documented in the ROD.

The ROD is a decision document that provides the risk exposure assumptions, describes the risk that requires remediation, identifies all reasonably anticipated future land uses, and documents the remedial alternatives and the remedy selection. The development of the ROD plays a major role in ensuring that cleanup at a site is completed in a successful and cost-effective manner. The ROD is a legally binding agreement between the Navy and regulatory agencies and changing the ROD subsequent to signing is a relatively complicated process. For this reason, the ROD should be carefully developed so that unexpected technical, administrative, and/or regulatory issues can be addressed in the future without requiring a change to the ROD. Potential changes to RODs must be implemented through an Explanation of Significant Differences (ESD) or a ROD amendment, and these additional steps can be costly and time-consuming.

Because the overall content of the ROD is very similar to the FS, all of the concepts discussed in Section 3.0 for the FS should also be considered by an RPM during the drafting of the ROD. However, the ROD differs from the FS because it is a decision document that explains what remedy has been selected for a site. The ROD is required to cover several issues related to remedy selection including: (1) the rationale for the selected remedy, (2) a description of the selected remedy, (3) estimated costs, and (4) the expected outcome of the selected remedy. The drafting of the language in these sections is important for future optimization efforts as discussed below. More information on the content of the ROD can be found in the U.S. EPA's *Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Documents* (U.S. EPA, 1998).

Assuming that the optimization considerations provided in Sections 2.0 and 3.0 have been implemented in the FS, optimizing ROD flexibility consists of providing an “observational approach” and implementing these optimization concepts. This will allow adjustments and modifications to address uncertainties that are typically encountered during implementation of a remedy as additional site and performance data are collected. The iterative and dynamic nature of effective optimization necessitates incorporating flexibility in the ROD, which has been referred to as a “flexible,” “smart,” or “performance based” ROD. Flexibility associated with design and implementation of a remedial action is critical due to the uncertainty that is inherent with most remedial projects, and the requirements and conditions of a site will likely change over the course of a project (Koerner et al., 1998).

It is important that the language used in the remedy description allow for flexibility in technology transition and unit process selection. If the remedy description is written too narrowly, then there will be little room to make adjustments or changes in the future. A carefully written remedy description is key to the ability to implement a treatment train approach as site conditions change

over time. For example, remedial technologies such as six phase heating, bioslurping, and others often require off-gas treatment. The remedy description can state that off-gas treatment will be required and that several different options are available such as granular activated carbon (GAC), catalytic oxidation, and VOC-adsorbing resins. The wording used in the ROD should state what the preference is at the time given current site conditions, but recognize the potential need for a transition to other more cost-effective options over time. Likewise, the remedy description should also discuss the treatment train planned for remedial technologies such as a transition from in situ chemical oxidation for source area treatment to MNA for dissolved plume treatment.

Another important section of the ROD for incorporating optimization concepts is the required section on the expected outcomes of the selected remedy. This section is required to contain a discussion of expected outcomes in terms of resulting land and groundwater uses and risk reduction achieved as a result of the response action. This is the most appropriate place in the ROD to document performance objectives and the overall exit strategy for a site. As discussed in Section 2.0, a single technology is often not able to reduce groundwater contaminant levels to risk-based standards such as MCLs. Instead, a treatment train approach is often needed with the use of multiple technologies over time or at various locations. This section is an appropriate place to discuss realistic performance objectives for the selected remedy components and the need for technology transition as further operation is no longer cost-effective. It is recommended that this section include a clear and defensible definition of the performance objectives. This section should also include a flowchart with decision criteria for stopping further system operation or transitioning technologies. The documentation of this information within the ROD will provide an agreed upon framework for future operations between the Navy and regulatory stakeholders.

In conclusion, a flexible ROD will facilitate effective system design and implementation of the optimization concepts discussed in Section 2.0. These key concepts include treatment trains, performance objectives, optimization and exit strategies. Incorporating flexibility into the ROD will also help to avoid costly and time-consuming revisions via an ESD or a ROD amendment.

Flexible ROD for SVE System at a Southern California NPL Site

A southern California National Priorities List (NPL) site was found to have volatile organic compounds (VOCs) in soil and groundwater as a result of historic waste management practices. During the 1940s and 1950s, subsurface seepage pits were used to dispose of liquid and solid wastes collected from drains and sinks within buildings at the site. This was an acceptable waste management practice at the time; however, it resulted in the release of spent chlorinated solvents and other chemicals into the environment.

The Record of Decision (ROD) for the on-site impacted soils was signed in 2002. The ROD established the remedial action objectives at the site to cleanup VOCs in soil to the extent practicable in order to prevent their further migration to groundwater. Soil vapor extraction (SVE) was the selected remedy because it was the U.S. EPA-designated presumptive remedy for VOCs in soil and it had public and regulatory acceptance. The ROD was written in a flexible manner in order to enable future cost-effective operation of the SVE system. In the remedy description, granular activated carbon was noted as the current selection of the unit process for vapor treatment. However, other potential options were noted in the ROD and it stated that this selection could "be modified based on the concentrations of VOCs in extracted soil vapor." The ROD also established the following performance objectives for operation of the SVE system:

- ☐ Reduction of overall contaminant concentrations compared to baseline levels
- ☐ Mass removal to asymptotic levels (following appropriate optimization of the system)
- ☐ Operate only as long as cost-effective.

These performance objectives were defined in the ROD and a flowchart of the exit strategy was provided to document the decision criteria that would be used to measure the progress toward meeting the performance objectives. This flexible approach was approved by the regulatory stakeholders and incorporated in the ROD and the following ROD document.

Flexible Permit for the Pensacola Wastewater Treatment Plant

The benefits of a flexible ROD are demonstrated by the Pensacola Wastewater Treatment Plant (WWTP) revised RCRA permit. The RCRA permit, as a decision document, can be considered analogous to a CERCLA ROD. This permit was amended in 2000 and replaced previous, more rigid permit conditions that specified pump and treat as the corrective action. The revised permit included a contingency plan that allowed for flexibility in modifying the selected remedy, "...based on an analysis of site specific data and evaluation of remedial alternatives, such as additional monitoring, reestablishing location of temporary point of compliance wells, containment, additional source reduction, and/or enhanced bioremediation." Also, the permit was written in such a way that any additional source reduction activities would only require submittal of a treatment plan and not a revised permit. This flexibility represents a significant savings in both time and costs.

Since the revised permit was issued in 2000, the Navy issued a treatment plan to use Oxygen Release Compound (ORC[®]) to remediate a chlorobenzene hot spot. Additional characterization indicated that the hot spot was larger than expected and the Navy is currently preparing another treatment plan, including evaluation of alternatives, for additional source reduction at the chlorobenzene hot spot and at a chlorinated ethene hot spot. Concentrations associated with the chlorinated ethene hot spot rebounded after being treated with chemical oxidation (Fenton's reagent) in 1998. Based on the current understanding of site conditions, the source reduction for the shallow, localized chlorobenzene hot spot will likely consist of excavation and removal. The source reduction for the chlorinated ethene source area will likely be in situ treatment with potassium permanganate chemical oxidation or some other reagent having residual long-term effectiveness.

Checklist for Optimizing ROD Flexibility

Conceptual Site Model

- ☐ Contaminants, sources, and release information
- ☐ Contaminant extent, fate, and transport defined
- ☐ Human and ecological receptors identified
- ☐ Exposure pathways and exposure concentrations identified
- ☐ Geology and hydrology defined (including stratification and low permeability zones, aquifer characteristics, flow gradients and velocities, etc.)
- ☐ Land use assumptions identified
- ☐ DQOs developed

Remedial Action Objectives

- ☐ Focused on protection of human health and the environment
- ☐ Allow flexibility and do not dictate the choice and/or duration of a proposed remedial action
- ☐ Consider POC for contaminants

Target Treatment Zones

- ☐ Identify target treatment zones
- ☐ Focused on risk reduction (consider evaluating risk reduction versus cost of remedial alternative)
- ☐ Source zone(s) considered
- ☐ Protecting and/or treating near exposure points considered

Treatment Train

- ☐ Identify multiple technologies (i.e., treatment train) for each target treatment zone (contaminant concentrations change over time; therefore the most cost-effective treatment approach changes with time)

Performance Objectives

- ☐ Identify performance objectives for each component of the treatment train.
- ☐ Consider technology limitations, typical remediation performance, and cost-effectiveness.

Optimization and Exit Strategy

- ☐ Identify how performance objectives will be used to transition to the next treatment technology in the treatment train.
- ☐ Clearly indicate that optimization will be an ongoing process during system operation.
- ☐ Incorporate rebound evaluation period (e.g., 1 year for groundwater to evaluate seasonal variation)
- ☐ Incorporate a contingency for rebound (e.g., reinstate system operation if significant rebound is observed)

Miscellaneous

- ☐ Incorporate flexibility so that a transition to a new technology does not require an ESD or ROD Amendment.
- ☐ Incorporate an "observational approach" that will allow adjustments and modifications to the remedial action during implementation of a remedy as additional site and performance data are collected.

5.0 CONSIDERATIONS FOR OPTIMIZING REMEDIES DURING THE RD

This section will discuss general life-cycle considerations during the RD phase and how to incorporate these strategies for the optimal design of ex situ and in situ treatment technologies. A checklist is also provided at the end of this section that summarizes the key considerations for optimizing remedies during the RD.

After the ROD is signed, the RD phase of work is initiated. The RD includes preparation of engineering reports, work plans, technical drawings, and specifications to describe implementation of the selected remedy(ies). Upon approval of the RD by the Navy, the remedial action, or the actual construction and implementation of the selected cleanup alternative is initiated. More information on this project phase can be found in the *Remedial Design/Remedial Action Handbook* (U.S. EPA, 1995).

Unlike in typical water and wastewater system designs that require flexibility to expand with increasing future demand, the remedial system designs should incorporate flexibility to accommodate decreasing mass removal rate with time. The optimization of the RD for a selected remedy should involve planning for a transition from higher- to lower-cost process options or technologies over the lifetime of the project. In the beginning, process options or technologies that can handle larger volumes or higher concentrations may be needed, but their use will likely become prohibitively expensive over time. Therefore, a transition over time to lower-cost process options or technologies needs to be considered in the design process. Figure 5-1 shows that as part of an optimized RD, RPMs should consider the life-cycle design of the selected remedy. The selected process options or technologies should be designed for extended maximum efficiency over the complete duration of the project. Remediation systems are often designed for the “worst case” initial conditions, which results in high initial capital costs and potentially higher O&M costs due to increased energy demands and other factors. A proper life-cycle design will result in a more sustained mass removal rate over time and typically lower capital and total O&M costs in the long run.

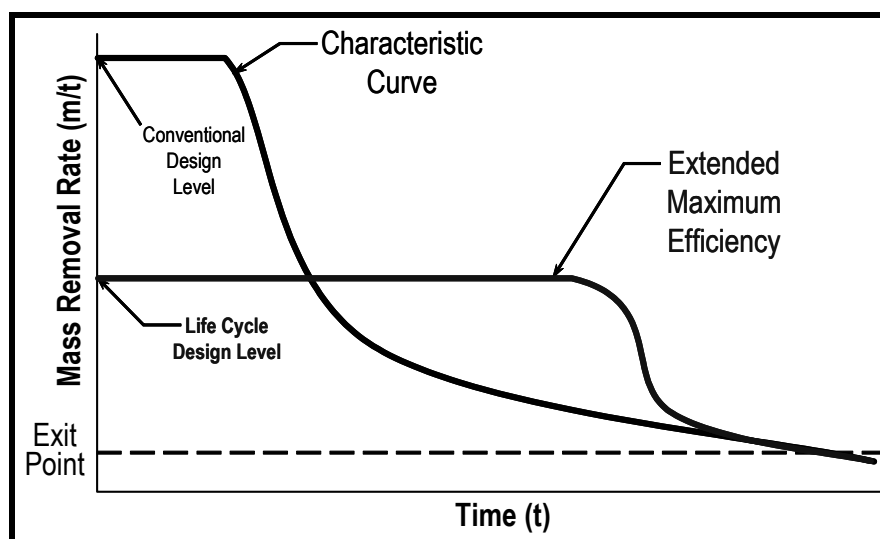


Figure 5-1. Life-Cycle Considerations for RD Phase

Another important aspect of treatment train optimization is the consideration and continual evaluation of site conditions, technological advances, and regulatory developments during the remedy selection and design phase. It is common for multiple years to pass between the FS and the completion of the RD. Much can change over that time period with respect to site conditions, advances in technologies, or changes in regulatory requirements. Because site conditions can change between the FS and RD phases, RPMs should consider the development of the CSM to be a continuous evolving process until site closeout is achieved. Additionally, data from the RI/FS may not be accurate enough and better data may be necessary to define source areas to be treated with in situ technologies. For example, a membrane interface probe followed by confirmation sampling with a Geoprobe™ could be used to better define contaminant extent prior to implementation of in situ chemical oxidation.

The CSM should be updated continually throughout the remedial process based on additional site data, changing risk assumptions, and other dynamic factors. This process should be included as part of the optimization process so that remedies are not implemented based on outdated or incomplete information. This process may include the evaluation during the design process of additional site data, literature reviews of current technologies (including proceedings from remediation conferences), on-site testing, or other input from separate sites that have similar contaminants or similar technologies. Attention to continuing process evaluation will help to avoid potential setbacks in remedial design implementation that can easily be avoided by basing the design on the best available information. Although the remedial design process may be constrained within the CERCLA framework, there is room for an evolving CSM and the iterative process of continuously optimizing and updating the remedial selection/design based on new information.

5.1 General Optimization Strategies

The life-cycle of a project is an important consideration in designing a cost-effective system due to the changing requirements that can occur at a site during the remedial phase. Most remedial systems have a life span of less than 10 years, but specific pieces of equipment within a treatment train may be needed for only a matter of months. The duration for which each piece of equipment of a remedial system is expected to be needed plays a significant role in developing a cost-effective design. Several design considerations and general measures for reducing the cost of remediation systems are described below:

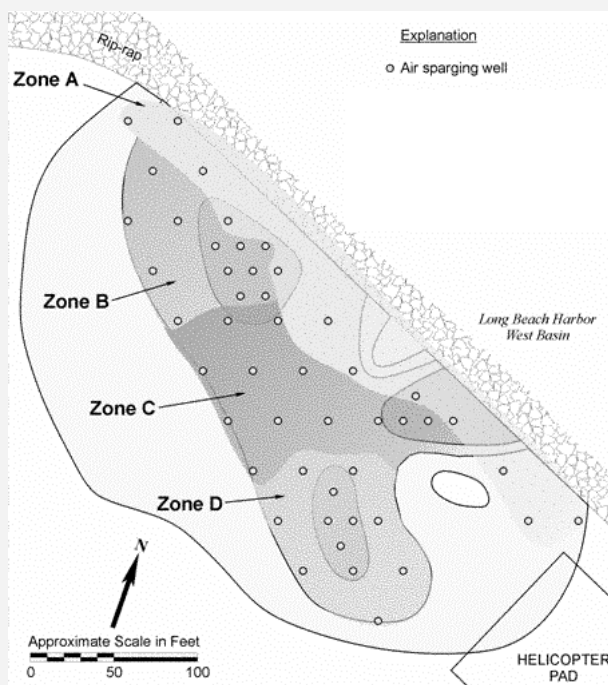
- ❑ **Lease Equipment** – Lease rather than purchase larger, expensive system components or equipment that will not be needed for the entire duration of a project. When the system is no longer needed, the leased equipment can be removed from the site and is no longer a cost to the project. It should be noted that leasing is most cost-effective for readily available equipment. The leasing of specialized equipment may result in increased costs over purchasing if the vendor must recover all of their costs from that given lease and not over multiple sites and clients.
- ❑ **Design Mobile Systems** – Remediation systems can be designed to be smaller and portable so that they can be used at more than one location within a single base or at several bases. For example, many remediation systems can be trailer or skid-mounted including free product recovery systems, bioventing units, and modular water treatment or injection systems.

- ❑ **Use of Passive Delivery Systems** – Under certain site conditions and for specific remedial action and performance objectives, utilizing passive delivery systems for the introduction of oxygen, other electron donors, or other remedial constituents as part of an active remedy can result in significant savings in capital and O&M costs. For example, passive bioventing avoids much of the capital and O&M costs associated with blowers/air compressors and associated piping for supplying oxygen to the subsurface by making use of natural vadose zone air exchange caused by daily and seasonal barometric pressure fluctuations and/or tidally influenced water table fluctuations.
- ❑ **Use Standard Designs and Parts** – In most cases, remedial systems can be designed using standard “off-the-shelf” components and parts. Use of standard equipment and parts is an important consideration in the remedial design process as it will ultimately help to keep the costs of a remedial system down and expedite system construction through the use of parts that are readily available and do not require custom manufacturing. Evaluate warranties and review historical performance data by checking references.
- ❑ **Use Inexpensive Materials** – The use of disposable or less expensive materials in the system design can reduce costs, provided they are compatible with the contaminants at a given site and meet the performance and engineering specifications. These materials can be used for piping, tanks, wells, and other pieces of equipment. In addition, site piping may be installed above ground where technically practicable to minimize installation and repair costs. In considering the materials and equipment items to incorporate into a remedial design, it should be noted that there are definite trade-offs between system capital costs and future O&M requirements. High quality, highly automated systems used in appropriate situations can significantly reduce future labor costs that result from system maintenance during long-term operation (Rast, 2001).
- ❑ **Plan for Intermittent Operation** – If possible, consider strategies such as pulsing or intermittent system operation to reduce the total treatment system capacity needed for the project. This approach is particularly applicable during the diffusion-controlled state to optimize mass removal associated with diffusion and desorption. This will likely result in lower capital costs. Trade-off in terms of the potential extension in the overall duration of system operations needs to be considered.
- ❑ **Evaluate Process Control Options** – The use of expensive remote telemetry equipment for process control typically is not necessary unless the system is located in a very remote location or has limited accessibility and is planned for relatively long-term operation. This type of equipment can sometimes significantly increase the capital cost of a system. However, there are definite trade-offs between system capital and O&M costs. High quality, highly automated systems used in appropriate applications can significantly reduce labor requirements and therefore result in overall life-cycle cost savings by reducing O&M costs (Nyer et al., 2000; Rast, 2001).
- ❑ **Develop Operation, Maintenance, Monitoring, and Optimization (OMMO)**
 - Manual** – The RD phase should include developing an OMMO manual. This manual should include how performance-based remedial objectives are achieved including the exit strategy. A checklist for system optimization is recommended and U.S. EPA guidance exists that is applicable when developing an OMMO manual (U.S. EPA, 1992; U.S. EPA, 1996b). An effective OMMO will require proper monitoring of system performance (including process monitoring of the treatment system and the monitoring

well network, if applicable) and inclusion of maintenance requirements and schedules. Also, the manual may need to be updated as the system operation progresses, based on system performance evaluations conducted during optimization of the system.

- ❑ **Permitting** – When obtaining permits, or complying with the substantive provisions of a permit, avoid committing to specific technologies or unit processes; rather, agree to discharge-based (mass or concentration) limits. This will allow the site owner to change technologies/unit processes, and/or once the permit limits are met, to discharge the waste stream without further treatment.

In Situ Treatment Life-Cycle Design at Former Long Beach Naval Shipyard IR Sites 1 and 2



AS/SVE was determined to be the most appropriate remedial option at IR Sites 1 and 2 at the Former Long Beach Naval Shipyard based on the nine-criteria CERCLA evaluation process.

The remedial action objective for groundwater was to minimize the potential for the migration of VOCs at concentrations that exceeded California Ocean Plan criteria into the nearby coastal waters. The AS/SVE system consisted of 48 sparge wells and 20 SVE wells.

Life-cycle issues were addressed to optimize the cost-effectiveness of system design, as follows:

- ❑ The target treatment area was selected as the portion of the plume with contaminant concentrations >10 times the California Ocean Plan criteria.
- ❑ The sparge wells were more densely spaced at 15 ft in the “hottest” areas to apply aggressive sparging for zones at >100 times the California Ocean Plan criteria.
- ❑ Dual-depth sparge wells installed in the same borehole to address shallow and deep layers of contamination.
- ❑ Four sparge zones were established (see Zones A, B, C, and D) and cycled operation was used between zones.
- ❑ Pulsed operation resulted in reduced capital costs because the selected equipment was one-quarter the size needed if all of the wells had been operated simultaneously.
- ❑ A literature review also indicated that increased mass removal rates may result from pulsed operation.
- ❑ Shutdown of the AS/SVE system has been approved by the State regulatory agency after 18 months of operation. The system is currently being monitored for one year to determine if there is rebound of the target contaminants. The system may be restarted under the RA-O phase or a request submitted for achieving the response complete milestone depending on whether or not significant rebound is detected, or a portion of the system may be restarted if the natural attenuation capacity of the aquifer is not sufficient to prevent migration of contaminant concentrations to the bay.

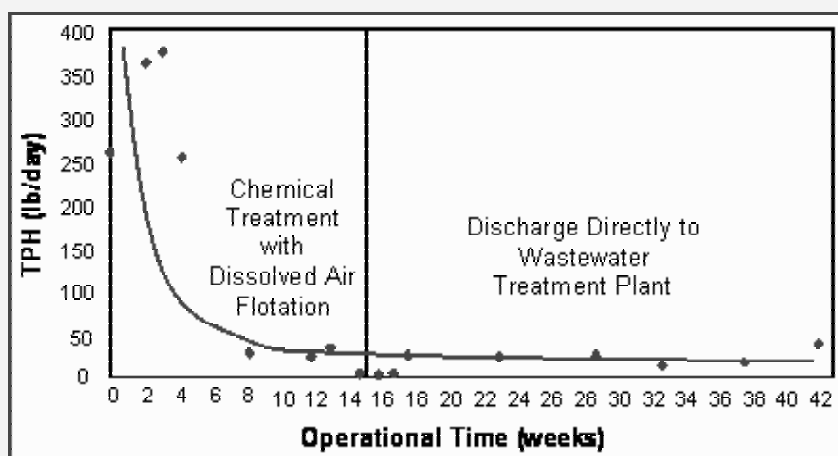
Ex Situ Treatment Life-Cycle Design at Coastal Systems Station (CSS), Panama City, FL

At a site in northern Florida, 63,000 gallons of petroleum hydrocarbons was released at a fire-fighting training pit, most of which was burned as part of the fire training exercises. These activities resulted in a ½-acre LNAPL plume with an estimated 500 to 5,000 gallons of recoverable LNAPL. The initial proposed remedy was interceptor trenches and sumps, but vacuum-enhanced free product recovery or bioslurping was later selected as a more optimal approach. The bioslurping system installed at the site consisted of 17 extraction wells, 12 groundwater monitoring wells, and unit processes for free product recovery and water and off-gas treatment. Several life-cycle considerations were taken into account in the design, as follows:

- ❑ Some of the equipment was leased to the Navy without the need to purchase the equipment.
- ❑ The system was designed for the expected short duration of LNAPL recovery.
- ❑ Polyvinyl chloride (PVC) was used instead of metal piping because of the expected short duration of the project.
- ❑ Aboveground piping was used to save installation costs and allow for less extensive secondary containment.
- ❑ The system was designed for average, not maximum, fluid recoveries and contaminant loadings.
- ❑ Each well had a flow control to adjust loading to the aboveground treatment equipment, depending on the LNAPL thickness observed in the well.
- ❑ Optimal treatment train design was used to implement a phased approach to water and off-gas treatment.

As listed above, optimal treatment train design for off-gas treatment and water treatment played a role in ensuring the cost-effectiveness of the remedy.

The figure shows the transition of the water treatment system from chemical treatment with dissolved air flotation (DAF) to direct discharge to the Base's WWTP. During the initial stages of the project, very high free product recovery necessitated the use of DAF to reach the appropriate discharge limits for total petroleum hydrocarbons (TPH). However, after 15 weeks, the recovery of LNAPL declined and the TPH levels in the extracted groundwater were below the appropriate discharge limits. The use of DAF was discontinued and the water was discharged directly to the WWTP. This resulted in an approximate cost savings of \$15,000 per month.



In addition, successful removal of LNAPL in the source area has enabled the natural attenuation capacity of the aquifer to be an effective remedy for dissolved-phase residual contaminants that had the potential to impact St. Andrews Bay (therefore, this site is an example of a source reduction and MNA treatment train).

5.2 In Situ Treatment Optimization Strategies

In situ treatment methods are a large part of the remedial strategy at many contaminated sites. Because they are below ground, in situ methods offer potential advantages over aboveground treatment systems, including reduced exposure of on-site personnel and the population to contaminants, minimization of aboveground support equipment that may interfere with site aesthetics or operations, reduced costs related to extraction and transport of contaminants and operation and maintenance of systems, and reduced liability of transferring contaminated media to other sites, e.g., landfills.

In situ treatment trains are an important part of the life-cycle design of groundwater and soil remedies because a single technology may often be unable to meet remedial action objectives in a reasonable time frame. Some in situ remedial technologies are best suited to reduce the mass in source zone or hot spot treatment, while other technologies are more suitable for the treatment of larger, more diffusely impacted areas. A remediation strategy frequently used involves a combination of in situ technologies, with active treatment in the source zone and passive treatment in the dissolved-phase plume. For example, chemical oxidation could be used to treat chlorinated solvents in the source zone, while enhanced bioremediation and/or MNA is applied downgradient to polish residual dissolved-phase contaminants.

As with aboveground treatment systems, concepts related to source and plume distribution, flow and mass transport, transformation and retardation of contaminants should be understood to achieve optimum results from in situ methods. In general, in situ methods involve treatment within the subsurface matrix that can be complicated by the unique geochemical and lithologic characteristics of the site. As with any treatment method, contact of the contaminant with the reagent or remedial mechanism is a key to successfully achieving remedial goals. Practically, this means site characterization should be sufficiently defined such that source/plume geometry, geochemistry, biological processes, and geologic lithology are sufficiently well understood to allow selection of the most appropriate delivery and treatment option. Failure to sufficiently understand these controlling variables may result in an inadequate design, failure to meet remedial objectives, and additional costs to collect appropriate data after the fact and change or modify the treatment system. In many cases, a pilot study may be warranted to evaluate response to treatment and determine critical design parameters prior to design and implementation of full-scale systems. Refer to Section 3.4 for additional information related to controlling variables and limitations that should be considered.

The examples in the next sections illustrate the importance of understanding site characteristics, determining technology specific design parameters, and implications for successful design, installation, and operation of in situ treatment methods. Also, the Naval Weapons Station, Charleston, SC and Marine Corps Logistics Base, Albany, GA case examples provided in Sections 2.3 and 2.4 illustrate optimization concepts described in these sections.

5.2.1 Source Characterization Impacts to Successful Treatment

Adequate characterization of the source zone is required for the successful design and implementation of in situ treatment technologies. As an example, at the Naval Submarine Base Kings Bay, treatment of a source of perchloroethene was hindered by incomplete characterization of the source area. Initial characterization of the subsurface used direct push technology to sample at pre-selected depth intervals to delineate the source of contamination. The intervals and areas selected missed significant portions of the contaminant source. During treatment by chemical oxidation, significant contaminant concentrations remained that required treatment. Follow-up

site investigation incorporated the use of continuous reading direct push technology that identified discrete zones of contamination not previously observed. Final treatment after further characterization resulted in a successful treatment.

Source zones typically represent relatively small areas compared to the area defined by the full extent of impact. In the case of impacted groundwater, source zones are sometimes difficult to locate, especially if the presence of DNAPL is suspected. For this reason, localized areas of elevated concentrations often are used as an indication of the presence of a nearby source. Various characterization technologies can then be applied to further delineate the source. For example, a membrane interface probe may be used to delineate the source and then a Geoprobe™ could be used to collect confirmation samples prior to designing the source reduction remedy. (Refer to the U.S. EPA Web site on innovative in situ characterization technologies at: <http://www.epareachit.org/>.)

5.2.2 Geochemical Impacts to Successful Treatment

Failure to account for the presence of certain geochemical constituents in groundwater systems can have negative impacts on technology performance. As an example, a Fenton's based chemical oxidation project at Naval Air Station Pensacola designed to treat chlorinated solvents in groundwater was deployed that failed to incorporate site geochemistry into the design of the reagent application. In this case, the site had elevated levels of ferrous iron in groundwater caused by the low pH conditions in the aquifer (<4) that was not properly evaluated prior to remedy implementation. Iron is a catalyst for the Fenton's reaction that is used to accelerate the reaction and generate radicals that oxidize the contaminants. Once the Fenton's reagent was injected into the subsurface, the high concentrations of iron in the groundwater caused the reaction to proceed very quickly at the injection point without reaching the intended radius of distribution. This initial round of treatment and mobilization was determined to be unsuccessful. After further evaluation of the site geochemistry, the reagent and catalyst were modified to account for the high ferrous iron in groundwater. The subsequent oxidation treatments with Fenton's reagent were deemed successful.

Similarly, aquifer redox conditions are critical to the successful design of enhanced bioremediation systems. For example, a shallow aquifer contaminated with chlorinated solvents and with oxic conditions frequently induced from infiltrating rainfall may require significantly more carbon substrate addition to develop and maintain anaerobic conditions favorable for reductive dechlorination. Such oxic conditions may also preclude the use of bioaugmentation that is sometimes considered for enhanced treatment of "DCE stalled" conditions as survival and growth of microbes injected for this purpose strongly favors an anaerobic environment.

5.2.3 Delivery System Design Impacts to Successful Treatment

A variety of engineered delivery methods are available to introduce treatment reagents to the subsurface for both source zone and dissolved plume treatment. The delivery system should be designed with site-specific conditions and remedial action objectives in mind. In situ treatment options can be classified as either passive or active. The distinction between these two categories is the degree of ongoing operation and maintenance of the treatment system. Passive implies minimal operation and maintenance as compared to active systems. Examples of passive delivery systems are permeable reactive barriers or biobarriers consisting of emulsified vegetable oil injected by direct push technology. For passive remediation systems in which transport of the contaminant to the treatment system occurs naturally, careful hydraulic evaluation should be made to ensure contaminants do not bypass the treatment system. Active delivery systems

include groundwater recirculation systems that extract contaminated groundwater from the subsurface, amend the water with treatment reagent, and inject the mixture back into the subsurface. The ongoing operation and maintenance requirements for recirculation systems should be considered when implementing these types of systems for in situ treatment.

5.3 Ex Situ Treatment Optimization Strategies

Treatment train optimization is also an important consideration for ex situ treatment systems that generate secondary waste streams and residuals that must be managed appropriately. Common outputs of remediation systems that must be managed include the following:

- ❑ **Air Emissions** – Typical air emissions from remediation sites include dust and VOCs. The selection, design, and operation of the VOC off-gas treatment system often plays a major role in the cost-effectiveness of a given remediation system. At many sites, off-gas treatment costs represent the largest portion of the total project O&M costs. It is important to optimize the selection of the vapor treatment technology because operating costs can be more than doubled if a less than optimal vapor treatment technology is used. Off-gas concentrations typically decline rapidly over time. Life-cycle concepts, therefore, need to be incorporated into the selection of off-gas treatment systems. Often, a phased approach is used at a site. For example, at a site with nonhalogenated VOCs, a thermal oxidizer might be used to combust the initial highly contaminated off-gas stream, followed by a catalytic oxidizer, and then granular activated carbon (GAC) or direct discharge. In addition, stringent regulatory requirements for off-gas treatment can drive costs at a remediation site. The air permit, or permit equivalency, should contain provisions to change out the off-gas treatment equipment over time and provide for direct discharge at safe levels. Once granted, this permit or permit equivalency will set emission limits and monitoring requirements for each type of equipment. The type of VOC off-gas treatment system appropriate for a given site should be made on a site-specific basis, based on the contaminant type, anticipated flowrate, mass loading, regulatory treatment requirements, and other factors.
- ❑ **Water Discharges** – Several site-specific factors play a role in the optimal selection of the type and capacity of water treatment units. These factors include contaminant types, influent/effluent concentrations, and natural water quality constituents. Typical water treatment technologies for organics include air stripping, GAC, chemical/ultraviolet oxidation, and biological reactors. Typical water treatment technologies for inorganics include chemical precipitation, ion exchange, adsorption, and electrochemical methods. Recommendations for the exact type of treatment process to be used are beyond the scope of this document, but additional resources are highlighted in the following text box. It is important that life-cycle design be incorporated into the selection and design of water treatment unit processes. A phased approach to water treatment should be considered so that the system can be modified over time in response to changes in flowrate or contaminant loadings. The phased approach can be achieved with modular treatment components that can easily be added or removed from the treatment system as appropriate (U.S. EPA, 1996c). The water discharge permit or permit equivalency should contain provisions that allow for transitioning between water treatment options as appropriate during the course of the remedial action.

Ex Situ Treatment, Design, and Optimization for Pump and Treat System, Trenton, NJ

A pump-and-treat system was designed for treatment of dissolved contaminants at a Naval facility in Trenton, NJ. Most of the design took place during the investigation phase to expedite the remedy and facilitate BRAC property transfer. Thus, system flexibility was a necessity for the remedial design. Thirteen monitoring wells that exhibited high hydraulic conductivity and high contaminant concentrations were converted for use as groundwater extraction wells. Groundwater flow models were used to determine a preferred pumping scenario that would allow capture of the contaminant plumes at a 60-gpm design flowrate. The treatment train was optimized by installing replaceable bag filters; instead of operating a solids removal unit consisting of pH adjustment, a clarifier, and sludge handling. This significantly reduced capital costs and simplified operation and maintenance requirements. A commercially available tray air stripper, sized for the expected contaminant loading, was included as part of the aboveground treatment train.

The system flowrate was set at 60 gpm, striking a balance between mass removal and plume capture. Most extraction occurs within the plume as opposed to downgradient. This helps the plant maintain a fairly high mass removal rate, even though the pumping rate is only 60 gpm. The permit equivalency for the air stripper/catalytic oxidizer was based on flowrate and contaminant loading, to allow flexibility in case contaminant concentrations decrease in the future. Similarly, if contaminant concentrations rise, the flowrate can be reduced without requiring permit changes.

Activated carbon units originally leased for an interim remedy were included as a polishing step in the final remedy. Once it was determined the units would be included in the remedy, they were purchased outright instead of continued leasing.

Spare parts for key components were purchased outright and kept in an inventory at the treatment plant. This allowed for timely replacement of a part when needed, minimized system downtime, and reduced costs by eliminating the need to have parts rebuilt under "rapid-turnaround" conditions.

- ❑ **Solid Wastes** – Excavation and disposal may be a cost-effective remedial technology at sites with shallow source areas, considering the many uncertainties associated with in situ technologies. The handling of contaminated soil and sediment removed from a site can be optimized in several ways. One method is to segregate stockpiles into different sections depending on the level and types of contamination. Soils or sediments that are appropriate for backfilling and/or surface restoration activities can be segregated from more heavily contaminated soils. Soil or sediments that are hazardous according to state regulations but not federal regulations can be segregated for treatment and disposal at the proper state-authorized facilities. Finally, soil or sediments that are hazardous, according to state and federal regulations, can be segregated for treatment and disposal at the proper federally authorized facilities. This approach will likely improve ease of handling by allowing "clean" soil or sediments to remain on site, and may also result in significant cost savings for treatment and disposal.

Resources for Treatment Train Design and Optimization

Additional resources include the following optimization guidance documents:

- ❑ Guidance for Optimizing Remedial Action Operation (NAVFAC, 2001)
- ❑ Guide to Optimal Groundwater Monitoring (NAVFAC, 2000)
- ❑ Navy's Natural Attenuation Software: <http://www.cee.vt.edu/nas/>
- ❑ Elements for Effective Management of Operating Pump and Treat Systems (U.S. EPA, 2002)
- ❑ SMART Site Cost Efficiencies in Remedial Action Operations and Long-Term Monitoring (NAVFAC, 1999)
- ❑ Remedial Process Optimization Handbook (U.S. Air Force, 2001)
- ❑ U.S. EPA's MNA Web site: <http://www.epa.gov/swenrust1/oswermna/index.htm>.

The following are interactive, multimedia tools that can assist RPMs in the selection of optimal treatment trains:

- ❑ NAVFAC Technology Transfer – T2 Webpage – This Web site includes a series of web-streaming multimedia tools to enhance the exchange of T2 information. These new tools include animated graphics, video, audio, electronic pictures, as well as text and Web links. Link to: <http://enviro.nfesc.navy.mil/erb/>.
- ❑ VOC Off-Gas Treatment Technologies Database – This tool provides technology descriptions, schematic diagrams, costing information, and potential vendors for seven different off-gas treatment processes. Link to http://enviro.nfesc.navy.mil/erb/restoration/technologies/sel_tools/main.htm.
- ❑ Ex Situ Groundwater Treatment Technologies Evaluation Tool – This tool is used to evaluate and compare extracted water treatment technologies by providing technology descriptions, schematic diagrams, and costing information. The tool also helps the user identify applicable site-specific treatment trains. Link to http://enviro.nfesc.navy.mil/erb/restoration/technologies/sel_tools/main.htm.

RD Optimization Checklist

Conceptual Site Model

- ☐ Contaminants, sources, and release information
- ☐ Contaminant extent, fate, and transport defined
- ☐ Human and ecological receptors identified
- ☐ Exposure pathways and exposure concentrations identified
- ☐ Geology and hydrology defined (including stratification and low permeability zones, aquifer characteristics, flow gradients and velocities, etc.)
- ☐ Land use assumptions identified
- ☐ DQOs developed

Target Treatment Zones

- ☐ Refine target treatment zones
- ☐ Source zone(s) considered (additional characterization may be needed)

Treatment Train

- ☐ Identify multiple technologies (i.e., treatment train) for each target treatment zone (contaminant concentrations change over time, therefore the most cost-effective treatment approach changes with time)

Performance Objectives

- ☐ Identify performance objectives for each component of the treatment train.
- ☐ Consider technology limitations, typical remediation performance, and cost-effectiveness.

Optimization and Exit Strategy

- ☐ Identify how performance objectives will be used to transition to the next treatment technology in the treatment train.
- ☐ Clearly indicate that optimization will be an ongoing process during system operation.
- ☐ Incorporate rebound evaluation period (e.g., 1 year for groundwater to evaluate seasonal variation).
- ☐ Incorporate a contingency for rebound (e.g., reinstate system operation if significant rebound is observed).

Miscellaneous

- ☐ Consider cost-effectiveness of leasing equipment rather than purchasing as contaminant concentrations may decrease rapidly.
- ☐ Design mobile remediation systems.
- ☐ Use of passive delivery systems when cost-effective.
- ☐ Standard designs and parts are appropriate in most cases.
- ☐ Use of inexpensive materials may be applicable for more technologies that are implemented for a short duration.
- ☐ Plan for intermittent operation to decrease capital costs and improve cost-effectiveness during the diffusion-controlled state.
- ☐ Evaluate process control options, realizing that remote systems are not necessarily the most cost-effective.
- ☐ Develop OMMO Manual.
- ☐ Avoid committing to specific technologies or unit processes when obtaining permits, or complying with the substantive provisions of a permit.
- ☐ For active treatment technologies, identify means of optimizing VOC off-gas treatment, process water treatment and disposal, and solid waste treatment and disposal.

6.0 CONCLUSIONS

The following are the major conclusions of this guidance document and recommendations for RPMs regarding the optimization of remedy selection and remedial design:

- ❑ **Incorporate CSM and Target Treatment Zone Concepts into FS, ROD, and RD** – A complete picture of site conditions and the selected target treatment zone will provide a strong foundation for remedy selection and design. The CSM should be continuously updated to accurately represent the site conditions as new performance data are collected. This data should be regularly analyzed to refocus remedy selection and design. This “observational approach” will lead to more cost-effective site cleanup.
- ❑ **Develop and Establish Performance Objectives in the FS, ROD, and RD That Are Distinct from Remedial Action Objectives** – Remedial action objectives should be focused on the protection of human health and the environment and should not dictate the choice and/or duration of a proposed remedial action. Performance objectives should be developed for each component of a treatment train and should incorporate consideration of technology limitations, typical remedial performance, and cost-effectiveness.
- ❑ **Incorporate a Treatment Train Approach and Life Cycle Design Concepts into the FS, ROD, and RD** – Multiple remedial technologies are often needed to achieve cost-effective remediation at a given site. The FS and ROD should identify multiple technologies for each target treatment zone. Therefore, as contaminant concentrations change over time, the project can adapt to employ the most cost-effective treatment technologies and/or unit processes. The use of a flexible ROD with an appropriately tailored discussion of the selected remedies and expected outcomes will allow for these changes to be made in a timely manner. The RD should then provide the design details that incorporate life cycle design considerations and a treatment train approach.
- ❑ **Provide for Optimization and an Exit Strategy in the FS, ROD, and RD** – RPMs should consider negotiating with supporting regulatory agencies to develop defensible exit strategies for remedial actions at their sites. The use of exit strategies will help to prevent prolonged and costly operation of a remediation system beyond its useful life. The exit strategy criteria should be first considered during the remedy selection phase in the FS and then documented in the ROD and RD documents.

Navy policy has been developed in conjunction with this guidance document to facilitate effective optimization. The NAVFAC Optimization Workgroup recommends an independent optimization review as part of the FS and RD. This review should focus on the appropriate implementation of the optimization concepts presented in this document. The following options will be available to the RPM for the optimization review (or combination thereof):

- ❑ NAVFAC Cleanup Strategy Review or Optimization Evaluation (coordinated through the NFESC)
- ❑ Internal Technical Review
- ❑ Contracted, Third-Party Review.

One of these options must be specified within the NORM database and associated costs must be incorporated into site budgets. Additionally, optimization will need to be considered by the RPM as part the acquisition strategy. This may require use of several contracting vehicles, incremental funding, and performance goals for the contractor to implement optimization.

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